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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

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Issue of Journal. The Journal is issued in six parts per volume, commencing in February of each year, with occasional extra numbers when necessary. The Title Page, Table of Contents and Index to each volume are published in the first issue of the succeeding volume.

Members whose subscription is not in arrear receive the Journal free of cost, and additional copies are charged at the rate of 7s. 6d. per part, unless otherwise stated. A member whose subscription is not paid by June 30th of the year for which it is due is considered to be in arrear.

Changes of Address. Members are requested to notify any change of address to the Secretary.

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Authors of papers published in the Journal are entitled to receive 25 free reprints of their contribution. Further copies may be obtained on payment and orders for these should be sent to the Secretary when the manuscript is forwarded to the Editor. The free reprints do not include any discussion which may be published with the paper, but authors may have such discussion included in their reprints on payment of the additional cost.

Galley proofs of the paper to be read at a General Meeting are available at the time of the meeting, but members desirous of receiving such galley proofs in advance should apply to the Secretary.

Binding of Journals. Members desiring to have their Journals bound in cases should send them, together with a remittance of 5s. 6d. per volume, to Messrs. Speaight & Sons, Ltd., 98, Fetter Lane, London, E.C. 4. A charge of 7s. 6d. will be made for binding Vol. 10, 1924. Remittance in all cases must accompany the order.

Abstracts. Abstracts of the more important articles and patent specifications are published with each issue of the Journal, this supplement being paged independently of the transactions. Members desiring to have the Abstracts printed on one side of the paper only can be supplied with uncorrected galley proofs at a charge of 10s. per annum per copy, payable in advance.

Medals. The Redwood Medal is awarded, at the discretion of the Council, to the person who shall have made the most meritorious contribution to petroleum technology, in the form of a paper or papers published in the Journal of the Institution, during two successive sessions, preference being given to original work and to papers which have been read before the Institution and discussed. The award is not confined to members of the Institution and may be withheld if no contribution is considered to be of sufficient merit.

A medal and a prize of five guineas is awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented the best paper during the session.

Research Fund. The sum of £400 is allocated in each calendar year to the advancement of Research in Petroleum Technology and its basic sciences, and the Council are prepared to receive applications for assistance from this fund.

Applications from persons proposing to engage in research in any university or other teaching institution must be supported by the professor under whom the applicant will be working.

Applications from Associate Members, Students or Associates of the Institution of Petroleum Technologists and non-members, not proposing to engage in research in any university or other teaching institution, must be supported by a Member of the Institution or other responsible person.

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Applications for grants from this fund will be considered in June and December of each year and must be received by the Secretary not later than June 1st or December 1st respectively. Application forms may be obtained from the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2.

Advertisements. Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. Thomas Tofts, 93 and 94, Chancery Lane, London, W.C. 2. (Telephone No. Central 8106.)

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Appointments Register. A register of members requiring appointments is kept at the office of the Institution for the convenience of firms requiring the services of petroleum technologists, etc., it being understood that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library may be consulted between the hours of 11 a.m. and 4 p.m. daily. (Saturdays, 11 a.m. to 1 p.m.).

ADDITIONS TO THE LIBRARY SINCE LAST JOURNAL.

The Oil War. By Anton Mohr.

The Geology of the Island of Trinidad, B.W.I. By G. A. Waring and G. D. Harris.

Petroleum Engineering. By R. W. Phelps and F. W. Lake.

Manual of Mineralogy (Dana's). 13th edition. Revised by Wm. E. Ford.

Agricola's "De Re Metallica." Translated by Hoover.

Colloid Chemistry and its Industrial Applications. 4th Report of the Department of Scientific and Industrial Research.

Coal Tar Distillation and Working up of Tar Products. 3rd edition. By A. R. Warnes.

Oil Fuel Burning at Sea and on Land. By J. S. Gander.

Conversion of Coal into Oil. By F. Fischer. Translated by Dr. R. Lessing.

From Geological Survey of India :—

Records of the Geological Survey of India. Vol. LIX., Part III. 1926.

From Junior Institution of Engineers :—

Journal and Record of Transactions, Vol. XXXVI., 1925–26.

From Mr. P. J. M. Larranaga :—

Successful Asphalt Paving. By P. J. M. Larranaga.

From Mr. Alfred Wirth :—

Drilling Aid Book. (Erkelenzer Bohr-Hilfsbudh der Maschinen- und Bohrgerate-Fabrik.) By A. Wirth and Co. 1922.

For Review :—

The Scientific Principles of Petroleum Technology, 1926. By Dr. Leo Gurwitsch. Translated and revised by Harold Moore.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

It is announced that on the impending resignation by Lord Greenway of the Chairmanship of the Anglo-Persian Oil Company, Sir JOHN CADMAN, K.C.M.G., will assume this office.

Mr. W. G. WATKINS has been elected a Fellow Architect and Fellow Surveyor of the Incorporated Association of Architects and Surveyors, London.

Mr. W. W. CONNOR is in Mexico.

Mr. H. S. DENNY has left for Canada and hopes to return some time in April next.

Lieutenant S. J. FORTESCUE, R.H.A., has returned from Burma.

Captain F. J. TABOR FROST has left England for South Africa and Southern Rhodesia.

Mr. E. D. IRVING is on his way to Peru.

Mr. C. O. F. JENKIN is now in California.

Mr. A. D. JONES has returned from Burma.

Mr. E. LAWSON LOMAX has left for Egypt for about two months to recuperate after his severe illness.

Mr. T. G. MADGWICK is in Canada.

Mr. C. B. MCKEEVER is now in Bogota, Colombia.

Mr. R. M. S. OWEN is in Venezuela.

Mr. R. H. PARNELL is on his way home from Assam.

Mr. J. M. PENNEY has returned from Colombia.

Mr. E. COOPER SCOTT is now in Trinidad.

Mr. A. HEDLEY WILLIAMS has returned from Estonia.

Mr. W. A. GUTHRIE is now in Scotland.

Dr. J. A. L. HENDERSON is now home from the West Indies.

LORD GREENWAY, Sir JOHN CARGILL, Mr. W. FRASER and Mr. W. C. MITCHELL are on a visit to Persia.

The Secretary will be glad to receive information as to the whereabouts of the following members :—G. R. CLARK, Lieutenant C. N. COLSON, R.N., J. A. GREENE, C. E. JOBLING, A. MAYFIELD, Engr.-Comdr. W. T. PAREZ, R.N., R. J. STALLARD, S. STOCK, and B. G. YOVANOVITCH.

OBITUARY.

H. E. NICHOLS.

It is with great regret that we announce the death of Mr. H. E. Nichols, at Mohammerah, Persia, on January 25th, 1927.

Mr. Nichols had been a member of the Board of Directors of the Anglo-Persian Oil Company since 1915, and at the time of his

death was also head of the Production Department of that Company. In addition to his position with the Anglo-Persian Oil Company, he also held Directorships in many of the associated companies, and had been a member of this Institution since 1919.

Mr. Nichols' energy and capacity for detail were of great value to the Anglo-Persian Oil Company, particularly in enabling them to meet the ever-increasing demands for oil supplies during the National emergency of the Great War, and his loss to them is irreparable.

Personally Mr. Nichols was of a singularly retiring nature, unusually kind and generous in character, and his many friends and colleagues in the British oil industry will deeply regret his early demise, after a sudden illness of only a few days, while on a visit to his Company's properties in Persia. His widow and two daughters survive him, and to them we extend our deepest sympathy in their great loss.

VISCOUNT BEARSTED OF MAIDSTONE.

The passing of a notable figure in the petroleum industry is regretted in the death, at the age of 73, of Viscount Bearsted, who passed away on January 17th, 1927, after a long and painful illness.

The founder of the Shell Transport and Trading Company in 1897, Viscount Bearsted subsequently brought about the amalgamation of that Company with the Royal Dutch Company.

His public activities were many. In 1891 he was made an Alderman of the City of London, in 1894 he was elected Sheriff, and in 1902-3 he served as Lord Mayor of London. He was knighted in 1898, and his Viscounty was bestowed upon him in 1925.

SECOND (TRIENNIAL) EMPIRE MINING AND METALLURGICAL CONGRESS.

The first session of the Congress will be opened in Montreal on Monday, August 22nd, 1927, by the Right Honourable Sir Robert S. Horne, G.B.E., K.C., M.P., who has indicated his acceptance of the office of Honorary President of the Congress.

The Congress will be in session for six weeks and in addition to the meeting in Montreal, further meetings have been proposed in Sydney, Toronto, Winnipeg, Calgary and Vancouver.

Plans are also being made for the delegates to visit some of the principal mines and metallurgical plants in the Dominion, as well as some of the chief beauty spots.

STANDARD METHODS OF TESTING PETROLEUM AND ITS PRODUCTS.

Report of the Standardization Committee, giving details of Methods of Test for Petroleum and Its Products.

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DECENNIAL INDEX, 1914 to 1924.

The complete index to the first ten volumes of the Journal of the Institution contains some 10,000 references to subjects and localities.

Price: 7s. 6d. net.

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THE PETROLEUM INDUSTRY.

A brief survey of the Technology of Petroleum based upon a Course of Lectures given by Members of the Institution of Petroleum Technologists at the Petroleum Exhibition, Crystal Palace, 1920.

This work will be found of value to students and those desirous of obtaining an elementary knowledge of the Technology of Petroleum.

A few remaining copies for disposal at 2s. 6d.

REPORT OF THE EMPIRE MOTOR FUELS COMMITTEE.

The complete Report of the Empire Motor Fuels Committee, containing valuable data relating to Fuels for Internal Combustion Engines.

A few copies are still available to members only at 1s.

All the above to be obtained from the office of the Institution,

ALDINE HOUSE, BEDFORD STREET, STRAND, LONDON, W.C. 2.

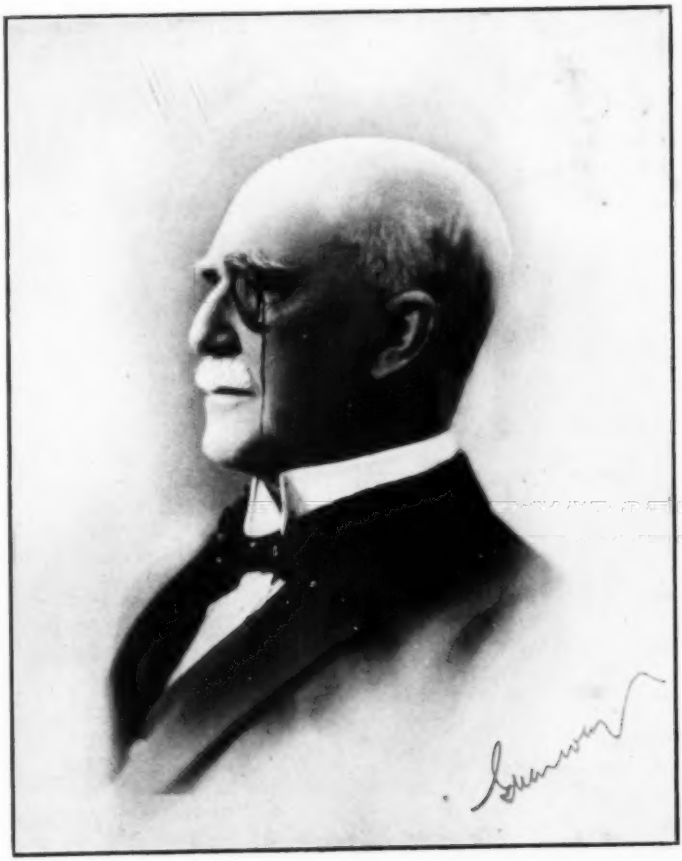
THE RIGHT HONOURABLE LORD GREENWAY OF STANBRIDGE EARLS.

It is with great pleasure that we congratulate a distinguished Past-President of the Institution on the signal honour of a Baron of the United Kingdom, conferred upon him by His Majesty The King.

Lord Greenway's interests in the Oil Industry embrace the Chairmanship of the Anglo-Persian Oil Co., Ltd., the British Petroleum Co., Ltd., The Homelight Oil Co., Ltd., The British Tanker Co., Ltd., The Petroleum Steamship Co., Ltd., The National Oil Refineries, Ltd., Steaua Romana (British) Ltd., The First Exploitation Co., Ltd., The D'Arcy Exploration Co., Ltd. He is also a London Director of the Burmah Oil Co., Ltd., and a Director of Scottish Oils, Ltd., North Persian Oil, Ltd., Turkish Petroleum Co., Ltd., The Société Générale des Huiles de Pétroles (Vice-President), The Tanker Insurance Co., Ltd., and of various other companies.

Lord Greenway went to India in the year 1885, and retired thence in 1908. During that period he played a considerable part in the industrial development of that country, more particularly in the production of Coal, Oil, Tea and Cotton goods, and the firms with which he is associated have also been largely concerned in the import and export trades of India and the Persian Gulf. Since his return to this country he has occupied a prominent position in City banking and mercantile circles. He has more particularly concentrated his attention on the extension and development of the Anglo-Persian Oil Co., Ltd., now one of the most important assets of the British Empire, and of its numerous associated Companies, and in the promotion of British commercial and industrial interests generally in Persia and Mesopotamia. It was at his instance that the British Government were persuaded in 1914 to provide the additional capital necessary to prevent the Persian Oil Concession from falling under foreign control, a step whereby the nation has not only been able to safeguard its supplies of Navy fuel, petrol, burning and lubricating oils, but by which it has secured an investment of enormous potentiality and one which has already proved to be of greater importance and of a far more remunerative character than that of the Suez Canal.

The honour of a baronetcy was bestowed upon him in 1919 by His Majesty the King in recognition of valuable services rendered by him to the Country during the war, and the decoration of Grand Officer of the Order of the Lion and Sun has been conferred on him by H.I.M. the Shah of Persia, for services rendered to that country. On January 1st, 1927, he was created a Baron of the United Kingdom of Great Britain, and has assumed the title of Lord Greenway of Stanbridge Earls.



THE RIGHT HONOURABLE LORD GREENWAY OF STANBRIDGE EARLS.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The Ninety-Seventh General Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, December 14, 1926, Sir Thomas Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S. (President), in the Chair.

The Secretary read the names of the following members who had been elected since the last meeting :—

Transferred to Member.—John Albert Bullbrook, Frank Benjamin Lea, Arthur Douglas Lumb.

Associate Members.—Morris Edward William Miller, Sidney Thomas Minchin, Stanley R. Wilson.

Students.—Leslie Howard Appleby, Alan Stuart Bridgwater, Stephen Edward Coomber, Geoffrey Gilbert Tombleson Crowe, Temple Ben Crichton Harris, Kenneth Ernest Humphrey, Morris Kamenetsky, James Anthony Gerrard McCluskey, Reginald Panisset, Eric Francis Haywood Spencer, Hallowell Charles Hermann Thomas, Wilfred Richard Wiggins, Charles Avalon Hinvest Williams.

The paper to be read at the meeting was a joint one by Dr. W. R. Ormandy, Mr. E. C. Craven, Prof. I. M. Heilbron and Mr. H. J. Channon. He proposed to ask Dr. Ormandy to open the proceedings by giving a summary of the joint paper, and Mr. Channon would continue with some points in which he had taken special interest. Dr. Ormandy wished him to say that the paper had been prepared at very short notice to take the place of one by another author that was not ready. The authors did not desire, therefore, the members to regard it as in any way final or in a form which expressed their complete and mature views on the subject of the research.

The following paper was read :—

A Contribution to the Study of the Origin of Petroleum The Berginisation of Fish Liver Oils and Other Bodies.

By Dr. W. R. Ormandy, F.I.C., F.C.S., M.I.A.E., M.Inst.P.T., E. C. Craven, B.Sc., F.C.S., M.Inst.P.T., Prof. I. M. Heilbron and H. J. Channon, B.A., M.Sc., A.I.C.

Historical.

The first reference to the occurrence of a hydrocarbon in fish liver oils appears to be due to Tsujimoto (J. Chem. Ind., Tokio,

1906, 9, 953). In a further paper on this subject J. Ind. Eng. Chem., 1916, 8, 889) he reported obtaining large quantities of the hydrocarbon from the liver oils of *Squalus mitsukurii* and *Deania eglantina*, and gave it the name squalene because it occurred chiefly in the liver oils of the *Squalidæ* sharks. The physical properties of the substance were described, and from the analysis of certain derivatives, Tsujimoto ascribed to it the formula $C_{30}H_{50}$. Meanwhile, Chaston Chapman (J.C.S., 1917, 111, 56) reported that he had found in what was reputed to be a specimen of cod liver oil a large quantity of an unsaturated hydrocarbon. Enquiry showed that the oil had probably originated from the livers of *Centrophorus granulosus* and *Scymnorhinus lichia*, which had been caught off the Moroccan coast, and the oils from which had recently appeared on the Portuguese market. This hydrocarbon, which had similar properties to that described by Tsujimoto, was given the name spinacene from its occurrence in the livers of the *Spinacidæ* sharks, and the formula $C_{30}H_{50}$ from the analysis of a number of derivatives. The hydrocarbon was separated from the oil by distillation, was optically inactive and could be reduced to the saturated compound $C_{30}H_{62}$, which was, however, different from the normal hydrocarbon of that formula. In two subsequent papers (J.C.S., 1918, 113, 458; 1923, 123, 769) Chapman came to the conclusion that the formula $C_{29}H_{48}$ was in better agreement with the results obtained from the analysis of a number of derivatives than was $C_{30}H_{50}$, and he accordingly assigned that formula ($C_{29}H_{48}$) to spinacene.

In 1920 Tsujimoto (J. Ind. Eng. Chem., 1920, 12, 62) reported further results which he had obtained in investigating a large number of liver oils from the sharks of Japanese waters. Squalene was found to occur in varying amounts in many of these oils; the specific gravity of the oils containing any appreciable quantity of squalene was always less than 0·9 and in only three oils having a specific gravity greater than 0.9 was squalene present, and in these in negligible amounts. In some cases over 80 per cent. of the liver oil was found to consist of squalene which occurred chiefly in the *Squalidæ* sharks. The analysis of a number of squalene derivatives are reported, and Tsujimoto referring to Chapman's belief that the formula of spinacene is $C_{29}H_{48}$ points out that as squalene hexahydrochloride $C_{30}H_{50}6HCl$ has very similar properties to the corresponding spinacene derivative $C_{29}H_{48}6HCl$, and as spinacene had been obtained from the oil of the *Squalidæ* sharks, it is highly probable that Chapman's spinacene is identical with squalene. The further history of the hydrocarbon may be briefly summarised. The action of ozone on squalene was studied by Majima and Kubota (Jap. J. Chem.,

1922, 1, 9), who isolated a hexaozonide which on treatment with boiling water yielded carbon dioxide, formaldehyde acetone, laevulinic aldehyde, formic acid, succinic acid, laevulinic acid and two unidentified acids. These authors also studied the products of dry distillation of squalene as Chapman had done. Reference may be made also to a paper by André and Canal (Compt. rend., 1925, 181, 612), and to the work of Heilbron, Kamm and Owens (J.C.S., 1926, 1630—1644). The latter report the results of a long study of squalene and its derivatives, and come to the conclusion from a consideration of all the evidence available that squalene and spinacene are one and the same substance of the formula $C_{30}H_{50}$.

Chemical Nature of Squalene.

Brief reference will now be made to the chemical nature of squalene. For fuller information, reference must be made to the original papers already referred to. Squalene is an unsaturated hydrocarbon of the formula $C_{30}H_{50}$ and containing six double bonds. It is a colourless oil having the following properties which are taken from the paper of Heilbron, Kamm and Owens. Boiling point 240—242° C. at 2 mm., density $^{18°}_{18°}$ 0·8596, refractive index $n^{18°}D$ 1·4972, iodine value 377·6. It may be prepared from any of the oils in which it is present in quantity by saponifying the oil, extracting the unsaponifiable matter in the usual way, and purifying it by distillation. It is preferable, however, to distil the liver oil directly, as was done by Tsujimoto and by Chapman. If the liver oil be distilled at low pressure, an almost colourless distillate is obtained, and the distillation may be carried on until the appearance of white fumes shows that the glycerides are decomposing. In this way most of the squalene may be obtained without the necessity of preliminary saponification of the liver oil. The traces of fatty acids with which the distillate is contaminated may be removed by washing with alkali. The squalene so obtained is a colourless oil containing varying quantities of oxygen up to 1 per cent. This may be removed by treatment with phthalic anhydride or the pure substance may be prepared by the decomposition of the hexahydrochloride. (Heilbron, Kamm and Owens, *loc. cit.*) Squalene hexahydrochloride may be obtained as a crystalline mass by passing hydrochloric acid gas into a solution of squalene in acetone, and these authors report having separated the product so obtained into three components of different melting points but all having the composition represented by $C_{30}H_{50}6HCl$, from which the parent hydrocarbon $C_{30}H_{50}$ may be regenerated. This isolation of isomeric hydrochlorides would indicate that squalene itself is a mixture of isomers. Heilbron, Kamm and

Owens also report that another type of isomerisation of squalene is possible, for when treated with 95 per cent. formic acid, squalene undergoes cyclisation. It is not possible, however, to carry the cyclisation beyond the stage at which two double bonds remain.

The decomposition of squalene by heat has been studied by Chapman (J.C.S., 1923, 123, 769), by Majima and Kubota, and by Heilbron, Kamm and Owens. By dry distillation of squalene and fractionation of the product, the latter authors obtained not only members of the hemiterpene and monoterpene groups, but also sesquiterpenes and diterpenes and probably higher members of the same class. From a study of these fractions the authors conclude that squalene is a dihydrotriterpene, as do Majima and Kubota, and they suggest that one of the isomers present may have the structure $C(CH_3)_2{=}CH.CH_2.[(CH_2C(CH_3){=}CH.CH_2]_4CH_2.C(CH_3).CH(CH_3)$.

Distribution of Squalene.

As already stated, squalene is widely distributed among the Elasmobranchs chiefly among the *Squalidæ*. It may be of interest to record the names of those fish in which it has been reported to be present. *Squalidæ*, *Scymnorhinus lichia*, *Centrophorus granulosus*, *C. acus*, *C. calceus*, *C. scymnosus*, *C. atromarginatus*, *Centroscymnus coelolepsis*, *C. Owstonii*, *Centroscyllium ritteri*, *Etmopterus lucifer*, *E. Spinax*, *Zameus squamulosus*, *Cirhigaleus barbifer*, *Zameus foliaceus*, *Lepidorhinus kinbei*, *L. squamosus*, *Scylliorhinidæ*, *Pristiurus pilosus*, *Cetorhinidæ*, *Cetorhinus maximus*, *Chlamedoselachidæ*, *Chlamedoselachus anguineus*. It is absent from such of the rays as have been investigated. Results are about to be published showing that it is absent from the livers of the common fish of British waters. That it is not confined solely to the Elasmobranchs is shown by the fact that its presence has been reported in cod liver oil (Drummond, Channon and Coward, Biochem. J., 1925, 19, 1047). Further, it is not confined to the liver of the fish only, for Tsujimoto (J. Ind. Eng. Chem., 1920, 12, 73) reported its presence in the egg oils of *Cheamedoselachus anguineus* and *Lepidorhinus kinbei*, and Heilbron, Kamm and Owens find it present in the eggs of *Etmopterus spinax*, *Lepidorhinus squamosus* and *Scymnorhinus lichia*. The following figures are given by Heilbron, Kamm and Owens as the average values for the percentages of squalene in the liver oils of the fish mentioned. *Scymnorhinus lichia* 55 per cent., *Etmopterus spinax* 50 per cent., *Centrophorus granulosus* 80 per cent. and *Lepidorhinus squamosus* 65 per cent. The occurrence of fish liver oils which contain such a high percentage of hydrocarbon and which may contain only 20 per cent. of true fat,

is a fact of peculiar biological interest, and attention has been drawn to this in a paper by Channon (Biochem. J., 1926, 20, 400).

In that paper experiments are reported showing that the administration of squalene to rats results in a large increase in the cholesterol present in the liver. This may suggest that squalene is a precursor in cholesterol synthesis in the animal body, and further biological experiments are in progress with a view to confirming or disproving this hypothesis.

Since squalene is the first hydrocarbon, the presence of which has been reported in fish liver oils, it became of interest to enquire as to what products would result from treating it with hydrogen at high pressure, and the results obtained are reported in the next section of the paper. Reference is made to the fact that squalene might possibly be connected with the origin of petroleum by Spielmann (The Genesis of Petroleum. E. Benn, Ltd., London. 1923)

The Berginisation of Squalene.

The samples of squalene used in these experiments contained small amounts of ether. After removing the latter by a current of dry hydrogen the following constants were determined —

	d 20° C.	Ignition Temp. (Moore).
Sample 1	0·8560	.. .. 260° C.
„ 2	0·8557	.. .. 258° C.

The ether free samples were mixed together and had a viscosity of 77 secs. Redwood at 70° F.

The mixed samples were submitted to the Bergius treatment in a small bomb, and the resulting liquid produot gave the following results on examination —

$$d20° \text{ C.} = \cdot 8256$$

On distillation from a flask 57 per cent. of spirit boiling to 200° C. was obtained, 23 per cent. of kerosene 200—300° C. and a residue of heavy oil. The spirit fraction had a S.G. of 0·775 at 15/15° C., and on analysis showed :—

	Per cent.
Unsaturateds..	10
Aromatics	26
Open chain paraffins	24
Closed chain paraffins	40

The " unsaturateds " were determined by the loss to 88 per cent. H_2SO_4. Dr. F. H. Garner has since shown that this strength of acid removes aromatics when unsaturateds are present. All

the fractions appeared to bear a remarkable resemblance to fractions similar boiling range from natural petroleum.

This leading to a desire for the fuller examination of the hydrogenated product, a larger sample of squalene was obtained and submitted to the treatment as described below in a free translation from the report of the laboratory of the Deutsche Bergin A.-G.

Treatment of Squalene.

Weight of sample 400 g.

The treatment was carried out in a 2 litre autoclave. In order to cleanse the autoclave thoroughly from the products of former experiments, it was washed out successively with benzol, alcohol and ether. After thorough drying a blank experiment was done with 60 g. of the sample, and the resulting material put aside. The remainder of the sample was worked up in 3 portions :—

Reaction temperature	470° C.
,, time	1 hour.
Initial hydrogen pressure	80 atmos.

The pressure remained constant during the heating period, but on cooling to room temperature a fall to 63 atmos. was observed. From this it may be concluded that considerable decomposition and hydrogenation had taken place.

The liquid product amounted to 75 per cent. of the sample used. On opening the autoclave a strong odour of benzine was observed.

In the third experiment from 140 g. of sample was obtained 112 litres of gas (d=·280 air=1) of the following composition :—

CO_2	0·0% vol.
C_mH_n	0·6 ,,
H_2	70·8 ,,
CO	6·1 ,,
C_nH_{2n+2}	13·6 ,,
N_2	8·9 ,,

The hydrogen employed had a purity of 97 per cent. The hydrogen absorption amounted to 3·45 per cent. by weight of the sample treated.

The liquid product as received by the authors was a mobile fluid, dark amber by transmitted light, and had a green fluorescence :—

$$d\,20^\circ\ C. = 0{\cdot}8129$$

A water wash showed small amounts of organic acids together with a trace of free sulphuric acid. On washing with caustic potash solution 0·1 per cent. of phenols was obtained, which gave a white precipitate with bromine water of characteristic odour.

Distilled with a plain tube column about 60 cms. long, 59·3 per cent. of spirit boiling to 180° C. was obtained. The residue which was distilled from a flask gave 28·2 per cent. of kerosene boiling to 300° C. The residual heavy oil was distilled at a pressure of 6—3 cms. Hg, and gave 5·6 per cent. of thin oil, discoloured by spitting, and 2·0 per cent. of a viscous oil strongly resembling an asphaltic base lubricating oil. It was not found possible to freeze any wax from this oil, but it had a cold test of about —15° C.

The small residue in the distilling flask was a clear, dark resin, readily soluble in benzene, partly soluble in alcohol.

The petroleum spirit fraction was carefully examined, the aromatics and unsaturateds being determined by a method shortly to be published :—

S. G. 0·765 @ 15/15° C.

Fractionated 8 bulb column to	40° C. = 15%		
	40—95° C. = 20·9%		
	95—122° C. = 25·5%		
	Residue 38·6%		
Unsaturated hydrocarbons to	40° C.	0·7% vol.	
	40—95° C.	1·4% „	} 6·8%
	95—122° C.	2·1% „	
	122° C.	2·6% „	
Unsaturated hydrocarbons ..		6·8% vol.	
Benzene		1·0% „	} 17·9%
Toluene		5·1% „	
Xylenes, etc.		11·8% „	
Open chain paraffins		49·7% „	
Closed chain paraffins		25·6% „	
		100·0% „	

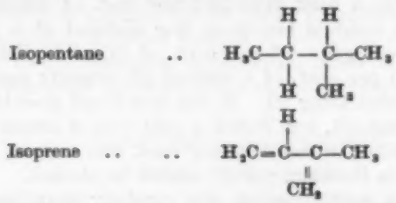
Aniline points were taken on the three aromatic fractions :—

Fraction.	Acid loss % vol. = Unsat. + Aromatics.	Rise of aniline point.
40—95° ..	11·5	11·3° C.
95—122° ..	28·3	26·4° C.
> 122° ..	37·2	33·9° C.

Since 1° rise in aniline point corresponds roughly to 1 per cent. vol. of aromatics, it is clear that the aniline point rise corresponds roughly to the sum of the aromatics and unsaturateds, and is useless for the purpose of separately determining the aromatic hydrocarbons.

The residue of saturated hydrocarbon had a specific refractivity of 0·5545 corresponding to 34 per cent. naphthenes. It was fractionated as far as possible with the 8 bulb column with the result shown in the graph.

The presence of isopentane is well marked, and this body shows a marked similarity in constitution to isoprene :—



The rest of the curve is very similar to the distillation curve of any petrol spirit. A small fraction was collected in the neighbourhood of 80° C. and showed ^{n}D 15° C.=1·399 pointing undoubtedly to the presence of cyclohexane.

As squalene is a terpene, it became of interest to see how a terpene would behave when submitted to the same treatment :—

The Berginisation of Pinene.

The d-pinene employed was obtained from Kahlbaum's :—

Engler distillation S. G. 0·868 @ 15/15° C.

Drop 151° C.	50% over @	154° C.
	80% „	156° C.
	90% „	160° C.
Dry @	95% „	183° C.

A sticky resinous residue was left.

The hydrogenation was carried out as described in the report from the laboratory of the Deutsche Bergin A.-G.

Treatment of Pinene (dextro).

Obtained from C. A. F. Kahlbaum, Adlershof bei Berlin. The treatment was carried out in a 2 litre autoclave :—

Weight of raw material	100 gms.
Initial pressure	80 atmos.

A blank experiment at 440° C. served to clean out the autoclave and three main experiments at 470° C. for the preparation of products.

During the heating at the reaction temperature no fall of pressure was observed, but on cooling to room temperature the end pressure was 68 atmos.

The yield of liquid products was 75 g.

100 gms. of pinene gave 126 litres of gas having a density of 0·254 compared with air.

COMPOSITION OF THE GAS.

CO_2	=	0·0%
CmHn	=	0·2%
H_2	=	75·8%
CO	=	4·0%
CnH_{2n+2}	=	12·8%
N_2	=	7·2%

The hydrogen employed had a purity of 97 per cent.

The hydrogen absorption amounted to 4 per cent. of the weight of the pinene. The liquid product as received by the authors was of a dark amber colour with strong green fluorescence :—

S. G. 0·817 @ 15/15° C.

On washing with caustic potash small amounts of phenols were removed, giving a white bromine precipitate.

The Engler distillation of the potash washed sample was as follows :—

Drop	38° C.	..	..	40% @	133° C.
1% @	53° C.	..	..	50% @	143° C.
2% @	59° C.	..	..	60% @	154° C.
5% @	70° C.	..	..	70% @	164° C.
10% @	86° C.	..	..	80% @	178° C.
20% @	109° C.	..	..	90% @	230° C.
30% @	123° C.	..	..	92% @	250° C.

Fractionated through a plain tube column about 60 cms. long, 79·7 per cent. of spirit was obtained boiling 25°—180° C., leaving a residue of 16·1 per cent. On distilling from a flask this residue gave 12·7 per cent. of kerosene fraction to 300° C., leaving a small amount of dark oil of moderate viscosity.

The spirit fraction boiling to 180° C. was carefully examined and showed :—

S. G. 0·780 @ 15/15° C.

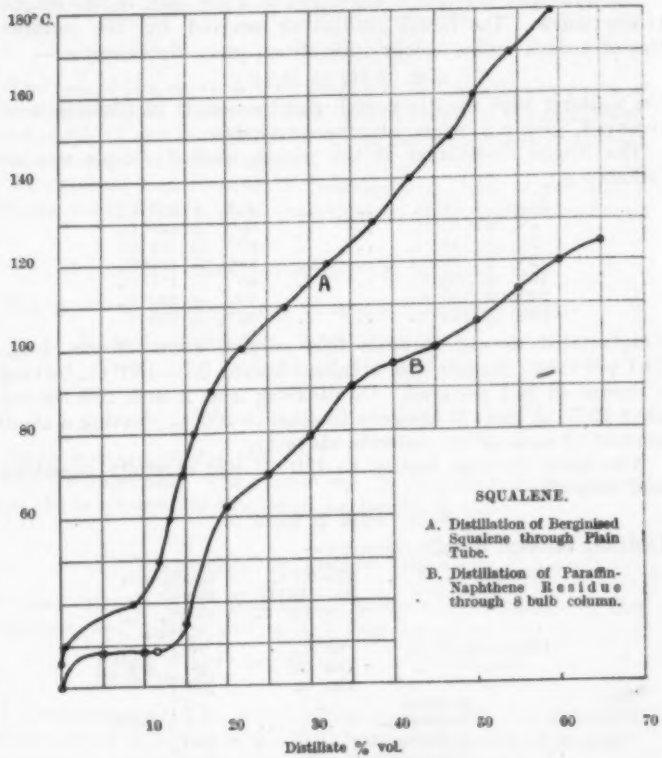
Distilled through 8 bulb column :—

Fraction	22—95° C.	19·4% vol.		
	95—122° C.	25·2% „		
	> 122° C.	55·4% „		
		% vol.		
Unsaturateds to	95° C.	1·9		
„ „	122° C.	2·1	9·5%	
„ >	122° C.	5·5		
Benzene		1·3		
Toluene		7·9	34·3%	
Xylenes, etc.		25·1		
Open chain paraffins ..		51·6		
Closed „ „		4·6		
		100·0		

The residue of paraffins left by washing with 98 per cent. sulphuric showed a specific refractivity of 0·5512 corresponding to a naphthene

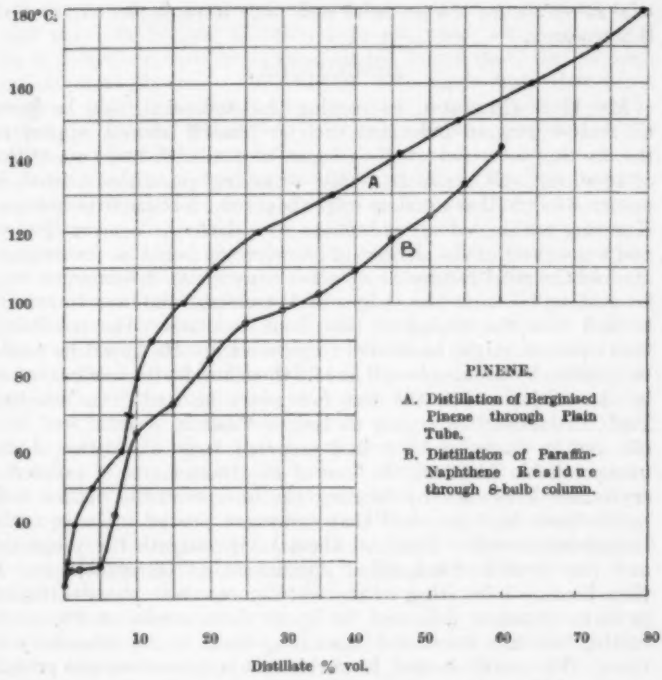
content of 7·8 per cent. This residue was distilled up to 143° C. through the 8 bulb column giving the distillation curve attached. The presence of isopentane is well marked, and the usual indications of hexane and heptanes. A small fraction collected at 80° C. showed D^{a} 15° C.=1·412, pointing to the presence of cyclohexane.

It will be noted that there is a great resemblance between the behaviour of squalene and pinene under berginisation conditions.



It is, however, quite impossible to repeat the conditions so absolutely in these bomb experiments as to make it worth while putting the results in parallel columns. There are considerable differences between the first and second experiment on squalene, though every effort was made to work under the same conditions of time, tempera-

ture and pressure, but these differences are quantitative and not qualitative. It must be pointed out that certain classes of lignite when subjected to berginisation are also converted quantitatively into oil and gas, and that the oil so produced is in every way similar to the oil produced from squalene except that instead of traces of phenols 20 per cent. of phenols may be present. It has been found that the higher phenols, when subjected to suitable



berginisation conditions, are converted into paraffins and lower phenols, and the lower the phenol the more soluble it is in water. If the conditions have ever existed which would convert fish liver oil into paraffin-like bodies, then similar conditions may have converted lignites into similar bodies, and the phenols being water soluble may have been washed away. It would appear from Bacon and Hamor that phenols have been found in a large number of petroleums. Engler also refers to the occurrence of phenols in

several German oils. The whole subject is one of great interest, and further work with hydrogenation under pressure may lead to results of real value in this difficult problem of the origin of petroleum.

Our thanks are due to the Deutsche Bergin A.-G. for carrying out the berginisation experiments and thus providing us with the raw materials which formed the basis of this work, also to the Fuel Research Division of the Department of Scientific and Industrial Research for the financial assistance towards the expenses of this research.

DISCUSSION.

Mr. H. J. Channon, in opening the discussion, said he knew no reason why an indvidual such as himself should appear at the meeting save that when he began to deal with large quantities of squalene, and began to realise what big quantities existed, it occurred to him that squalene might bear some relation to petroleum. Knowing nothing about petroleum he visited the nearest library, and was aghast at the amount of literature he found on the subject. He had the good fortune to obtain a copy of Dr. Spielmann's very interesting book on the Origin of Petroleum, and was interested to find that the author of that book mentioned the possibility that squalene might be related to petroleum. He hoped he would be forgiven by the members if he told them how he became interested in the subject. For the last few years he had been assisting Prof. Drummond in trying to isolate Vitamin A from cod liver oil, and in doing so they had prepared large quantities of the unsaponifiable fraction. In one of the fractions they isolated a crystalline substance by treating the unsaponifiable matter with hydrochloric acid gas, and that substance proved to be squalene hexahydrochloride. That led them to investigate the properties and the possible biochemical significance of the substance. It then became interesting to see whether squalene was distributed in more common fish, and he spent three weeks at Plymouth cutting out fish livers and examining them in his laboratory in town. The result showed, however, that squalene was not present in any of the common fish of British waters. Another interesting point was whether a fish synthesised this hydrocarbon or whether it was merely a product derived from the fat ingested. That was a question that could be readily settled in many cases, but in the one under discussion it was difficult. If the fish were not viviparous, the eggs could be taken and hatched out, and the fish could be fed on white fish for a number of months; it could then be ascertained at the end of that time if the amount of squalene in the fish was greater than in the original eggs. It

would further be noted that the sharks from which the hydrocarbon was obtained must have something very abnormal in their metabolism. He felt bound to regard the liver as being a very important organ from the point of view of fat metabolism. The members were doubtless aware that usually in fish liver oils 99 per cent. of the oil consisted of true fat and there was only 1 per cent. of unsaponifiable matter. But in shark liver oil there was 80 per cent. of hydrocarbon and only 20 per cent. of true fat, indicating that there must be a very abnormal fat metabolism in that particular fish. It became of interest to see what would happen if the hydrocarbon squalene were included in the daily diet of such an animal as the rat. Experiments were made from that point of view, and it was found that it caused a large increase in the cholesterol content of the liver, and this result suggested that the substance was related to cholesterol. If it were related to cholesterol one would expect perhaps to find squalene in the liver, because in some work he did a few years ago he showed that if an animal were given a diet which was absolutely devoid of cholesterol it synthetised all the cholesterol it needed. He therefore spent some time in looking for squalene in mammalian liver, and as a result of investigating some 4 cwts. of pig liver he found that no squalene was present but a substance of a very similar nature, which was not isolated in a pure state but only as a derivative, such as the hydrochloride and bromide. Owing to a variety of difficulties, it was impossible to obtain the original hydrocarbon, but he obtained a fraction which was approximately 80 per cent. pure. If that substance was distilled at very low pressures of 1 millimetre or more it broke down into a series of fractions which were almost identical with the fractions at which squalene broke down when distilled at atmospheric pressure. It appeared therefore that those two hydrocarbons—the hydrocarbon squalene and that present in the mammalian liver—were closely related. Further, the fact that squalene was a straight chain unsaturated compound which would give terpenes when distilled at atmospheric pressure suggested also a possible relationship to cholesterol, in that cholesterol was a terpene-like body. Further, as was said in the paper, squalene would readily cyclise; in other words, the straight chain would undergo ring formation.

The only other point he wished to mention was that Prof. Heilbron had been studying the hydrogenation of squalene with a nickel catalyst and had found that the double bonds seemed to be sectively saturated.

Prof. A. W. Nash said the experiments on the Berginisation of squalene and d-pinene which the authors had so ably brought forward were extremely interesting from the technical standpoint.

Dr. Ormandy had stated that the paper was prepared hurriedly, and therefore it was rather difficult to discuss it. He desired to suggest that as a help to elucidating the problem of the origin of petroleum the evidence produced was not sufficiently conclusive to do other than provide an excellent opportunity for the expression of conflicting opinions on the subject, into which he could not enter fully at the moment owing to the shortness of time available. His reason for discussing the paper at all was because more hydrogenation work of the kind described had been done at Birmingham than elsewhere in this country, and he wished to confine the few remarks he had to make to suggestions in regard to further experiments which he thought should be undertaken before any conclusions could be drawn, whether definite or otherwise. It would be seen from the distillation ranges in the pinene work, both before and after treatment, that definite disruption and also polymerisation must have taken place. It would be interesting to know whether the authors could give a possible explanation as to how the phenols were derived from the pure hydrocarbon, unless an impurity, such as oxygen, in the hydrogen gas was a possible cause. In that case he suggested that a nitrogen blank experiment would be helpful. He noticed that no fall in pressure was observed during the experiment, as was found in the case of the work on coal which the Birmingham University had carried out, although a substantial fall in the total pressure was noted, which fall, although not so great as in their coal-work, was certainly greater than when treating gas oil in a similar manner. He wished to ask the authors whether they considered that the hydrogen absorbed in the pinene work, and possibly in the other oils, was more rapid than in the case of the hydrogenation of coal, where a definite falling-off in pressure was obtained at the optimum reaction temperature. It would also be of interest if the authors would state how much of the hydrogen absorption had gone into methane formation and how much had been absorbed by the oil itself. That was a very important point, they had found, in the work they had done. There, again, he suggested that a nitrogen blank experiment would be helpful, not only to clear up the points he had raised, but also in view of Engler's work. Engler had shown that by merely distilling a Menhaden (i.e., of the herring species) oil at temperatures between 320° C. and 400° C., and under pressures varying from 4 to 10 atmospheres, hydrocarbons could be obtained. The distillate, which had a specific gravity of ·8105, contained paraffins from pentane to nonane, and, from its behaviour, naphthenes, aromatics and olefines were also considered to be present. The product was brown in colour and possessed a greenish fluorescence, and was evidently similar to the liquid obtained

by the authors. He suggested therefore that before the experimental evidence the authors had brought forward could be accepted as in any way confirming the fish origin of petroleum (a theory he knew the authors did not advance) further work would need to be done on the lines he had just indicated.

With regard to the argument by analogy advanced by the authors as to the possibility of lignite being the parent substance of petroleum, apart from his (Prof. Nash's) dislike of arguments of this kind generally, he would like to receive some experimental details of the examination of the crude liquid product derived from the Berginised special lignites to which the authors referred.

He hoped the members would appreciate that his views were put forward as constructive and not as destructive criticisms.

The question of the temperature and pressure necessary for the reactions to take place under natural conditions was one which he thought he had better leave for the geologists present to deal with, but he felt a little unhappy about the statement made that: "All the fractions appeared to bear a remarkable resemblance to fractions of similar boiling range from natural petroleum." If the comparison was based simply on the boiling range, such an expression was merely a measure of volatility. Such statements had been made in regard to other Berginisation products, and in some instances this physical property had completed the resemblance. If the authors' statement went deeper than that, he asked for more details as to the characteristics of the fractions and to which natural petroleum reference was made.

Dr. P. E. Spielmann thought the paper was of very great value, but that its connection with the problem with which it associated itself was rather gossamer-like in its links, and threw an indirect light on the various theories that had been put forward for the origin of petroleum. They were all valuable, and all in the direction in which one would look for the final explanation to come. It was found that both pinene, which was a vegetable substance, and squalene, which was a complicated pinene and an animal substance, gave on Berginisation a petroleum-like material, which suggested that both vegetable and animal substances might be the origin of petroleum. That was in direct opposition to Macfarlane, of America, who had written a book of 400 pages with the object of showing that fish were the origin of petroleum and that the vegetable origin was impossible. Again, a hint was obtained that there might be a great deal more in Hackford's theory; he suggested that vegetable material, when it was allowed to decompose freely under conditions, would form petroleum, but when it was decomposed in a network of cellulose and was held in place it gave rise to coal. Then there was a curious

observation made some time back in Germany in which a bituminous substance and a trace of paraffin were found at the roots of a pine tree. It was not very important, but there again, somehow or other, they were brought in contact with pinene, or something like it. The weakness of the work described by the authors was, he thought, the same as in all laboratory work where petroleum-like materials were synthesised under laboratory conditions—that they did not know how far they were justified in equating those laboratory conditions with what must have happened under natural conditions. In any future work that might be carried out very valuable, if indirect, evidence might be obtained that something of that kind could be effected. It would be remembered that Bergius, in the paper he read some 15 years ago, showed how cellulose, when heated under definite conditions, could be converted into something very much like coal, and from the time-temperature figures that he obtained he calculated the ages of the coalfields, assuming that the reaction took place at a temperature at which the world was likely to be during those periods. He thus arrived at a figure surprisingly close to what geologists estimated the age of the coalfields to be. There was a difference of a few millions of years, but a difference of a few millions of years was nothing in geological matters. If, in future work on Berginisation, it was possible to calculate back in the same manner, some very interesting figures might be obtained as to the possible time it took to produce petroleum, and if they were reasonably of the same order he thought indirect evidence would be obtained that such hydrogenation of fish oils might have taken place in the manner suggested. One point that would have to be accounted for was where all the spare hydrogen came from.

The President, in concluding the discussion, said that the paper had been prepared at short notice in order that there might be a subject for discussion at the meeting.

The question that was probably stirring the minds of some of those present in regard to the origin of petroleum was, he was sure, one that was also acting with a certain amount of inhibitory influence on the members as it was on him. The paper was in a sense a challenge on the question of the origin of petroleum. He did not think the challenge was in such a form that one would be justified in assuming it came under the normal Queensbury rules! So far there had not been put before them enough in the way of facts that were assured and at the same time representative of conditions in Nature that might be regarded as conditions that were sufficiently widespread to produce petroleum in commercial quantities. The fact that a petroleum, or a petroleum-like body, could be produced did not interest many people at the present

time, unless to that fact there could be added the simple multiplier that it was obviously so prevalent in Nature as to form a serious contribution to the supplies of petroleum. The text and the sermon were so unlike quantitatively—he did not say in quality—that he feared that at present they were entirely unjustified in embarking on any discussion regarding the origin of petroleum. There were, however, two or three points that he thought could be put roughly at the present time, and he made those suggestions with exactly the same excuse with which Dr. Ormandy started his paper, namely, that his remarks must not be taken too seriously. There were, for example, the questions of temperature, pressure, and time. A pressure of 400 atmospheres and a temperature of 400-odd degrees might easily be obtained at a depth in the earth of 12,000 feet or 15,000 feet. That would not be regarded as excessively deep. Certainly there were petroleum deposits at greater depths than that, although no attempt had been made to drill to that depth so far. He thought therefore it might be said roughly that, in regard to temperature, pressure and time, experimenters need have no fear that the earth could imitate and go a little beyond what was necessary in the conditions that were promised. With regard to the question of whether it could be treated as a serious source of petroleum, Dr. Ormandy had asked whether the species of shark which had yielded such large quantities of squalene was abundant at the time when oil was produced. It was well-known that sharks' teeth were quite abundant in many marine formations; indeed, it was because of the stability of the shark's tooth that so much evidence had been obtained of the existence of sharks. Other fish might have existed in very much greater numbers, because it took a large number of other fish to feed one shark. Presumably the shark did not live for nothing; if fact, it was frivolously suggested that because so much oil was found in the shark's liver, the preying tendency of the shark had some kind of resemblance to what innocent people sometimes thought was also the tendency of a big oil company; there was something predaceous about the nature of both. Sharks' teeth were found, but not in any quantity that would suggest an origin for oil in commercial quantities. One further step in the line of destructive criticism was that the sharks that were living now were not of the species that existed at, say, the beginning of the Tertiary period. The fact that certain species of sharks at the present time contained squalene did not prove that the older Tertiary sharks equally supplied the same kind of material.

Mr. Channon had mentioned one point which he thought was rather important, again in the direction of destructive criticism,

when he said that in many fishes the presence of squalene was rather to be regarded as abnormal than general. Assuming then that there were more fishes of other sorts than sharks, fishes could hardly be regarded as a normal and serious source of petroleum, because if conditions, say, in older Tertiary times were similar to those at the present time, again it would be found that there were more fishes without squalene than with it. On the whole, he did not feel that on the few facts which had been put before them, the members would be justified in taking up the challenge and treating it seriously along statistical lines as a test of the possible or probable origin of petroleum. He used the word "seriously" to indicate petroleum in commercial quantities, because that was the point that always had to be kept prominent. He did not wish to go any further into the discussion, because the members would appreciate that it was necessary to go only a very short distance in order to get into very deep water. A question was being dealt with which could be treated in two quite different ways. In one way, because of the fewness of the facts and data of a reliable sort one was not justified in drawing any conclusions; in another way, and for exactly the same reason, one was equally safe in coming to any conclusion he liked and adhering to it, knowing full well that nobody else could contradict him, for the reason that he also was supplied with an insufficient number of facts. He had stated the question in general terms in that way because, as he had previously said, the members were challenged to discuss on the origin of petroleum. Geologists did not hesitate to fight, in fact loved it, when an opportunity occurred, because of the kind of weapon that Nature had provided for them, but on the present occasion he did not think they could follow up the question seriously. The paper indicated that the subject represented the beginning of a research which might ultimately lead to a more serious consideration of theories regarding the origin of petroleum. And no research worker was worth his salt if he did not follow up every clue, however obscure and flimsy. He was certain, therefore, the members would desire him, as President of the Institution, to convey their thanks to Dr. Ormandy and his fellow workers for their suggestive paper.

The following written contribution was received from **Dr. V. Henny:**

The Berginisation experiments ably described by Dr. Ormandy are very interesting as such. I suggest that they would have been more complete and more conclusive if Dr. Ormandy had described also some control experiments, I mean experiments without addition of H. Engler, some 20 years ago, described the formation of petroleum-like bodies obtained by pressure distil-

lation, and I believe that it would interest all of us to be informed of the exact difference which the addition of H. makes in the pressure distillation of squalene and pinene. In addition, there is one point in the experiments on which I should particularly like to have Dr. Ormandy's view. It is the unexpected presence of phenol in the Berginised squalene and pinene and the presence of CO in the gases after Berginisation of these two products. Can this be due to anything else but impurities of the hydrogen employed, because I understand from the paper that the squalene and pinene were pure hydrocarbons? If so, it is curious that practically all of the oxygen present before the reaction should merely form CO with traces of phenol, and no other compounds containing oxygen.

Dr. W. R. Ormandy, in reply, said that Dr. Henny's communication on the subject of the paper was almost exactly on the same lines as those raised by Prof. Nash, in which he referred to the amount of phenols and asked where they came from if the squalene was a pure hydrocarbon. The fact was that the hydrocarbon as supplied to the authors contained approximately 1 per cent. of oxygen, which would be more than ample to account for the amount of phenols present. The H. employed contained 3 per cent. CO, which accounted for that found in the gas analysis. The suggestion that the experiment should be carried out in the presence of nitrogen was an obvious one, and it would prove of interest if done. If brown coal, lignite, or ordinary coal were heated in a retort with nitrogen instead of with hydrogen, coke and the ordinary products of decomposition were obtained. If it was done, however, under the right conditions with hydrogen, a large amount of oil was obtained, 90 per cent. more of the coal substance being converted into oil. What would happen with regard to squalene under those conditions could not be said until it had been tried, but a forecast which could be made with a great deal of certainty was that with a large amount of nitrogen instead of hydrogen it would split up into carbonaceous bodies and a good deal of coking would take place. It was quite clear that much more work would have to be done before a basis of fact would be arrived at upon which the situation could be adequately discussed. He had very little doubt that Mr. Channon and Prof. Heilbron would be very pleased to work in co-operation with Prof. Nash if he would like to continue the experiment; it was merely a question of their providing Prof. Nash with the necessary amount of raw materials. Clearly, the Berginisation Company could not be asked to continue the exprimeents which, however interesting they might be, scientifically had no cmomercial value, and which cost a good deal of time and money.

Prof. Nash had raised a question in regard to the rate of hydrogen

absorption. It was in his (Dr. Ormandy's) opinion impossible in bomb experiments to rely on the results of the recording gauges in dealing with the problem of the rate of absorption. He had found, for instance, that taking a specimen of coal and hydrogenising it in a retort, there was a distinct drop in pressure, showing that the absorption was taking place within an hour at which the temperature was again constant. On the other hand, working the same coal in a continuous machine, it was found it would run from 12 to 24 hours before a state of equilibrium was arrived at. In other words, it was a mass reaction, the course of the reaction and the equilibrium point were largely determined by the hydrogen partial pressure. Engler had pointed out that on distilling portions of herrings under pressure, paraffin-like bodies were formed, but in the present instance there was a conversion of some 98 per cent. or 99 per cent. of a substance into paraffin-like bodies of a well-known type. Dr. Spielmann, whose remarks were of very great interest, had asked where the hydrogen came from. That was a point that required consideration. He merely said that if hydrogen, pressure and temperature were provided, i.e., if the Berginisation conditions were provided, and if geologists could state if those conditions arose, then those results could be obtained. The President had rather been flogging a dead horse, so far as he was concerned, in the remarks he had made. He had never put forward the idea that fish oils, or fish liver oils, were the source of the paraffin oils of commerce. He merely said that fish liver oils, such as shark liver oils, when Berginised made those products, but he did not suggest that they occurred in such quantities as to be accountable for natural oil. His argument was rather in the direction of the fact that if it be admitted that such conditions of temperature, pressure and hydrogen ever were present as would convert a fish oil into a paraffin oil, then those same conditions would convert brown coals, lignite or bituminous coals into paraffin-like bodies over the whole gamut, from the light volatiles up to heavy lubricating oils, always supposing that the fact could be accounted for that the phenolic bodies had been removed by the action of water or some other means. His own feeling was very distinctly that if there was anything in the Berginisation process in Nature which had led to the formation of paraffin oils, it had been due to the treatment of lignites or similar bodies under those conditions.

He desired to emphasize that the authors had merely brought forward their paper as a contribution and, as he remarked at the opening of the meeting, a contribution could either be worth a trousers' button, or a ten-pound note.

On the motion of the President, a hearty vote of thanks was accorded to the authors, and the meeting terminated.

INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE NINETY-EIGHTH GENERAL MEETING of the Institution of Petroleum Technologists was held in the House of the Royal Society of Arts, London, on Tuesday, January 11th, 1927, Sir Frederick W. Black, K.C.B., B.A. (Lond.), Past-President, in the Chair.

The Secretary announced that the following had been elected members of the Institution :—

Members.—Richard Moore Beesley, Thomas Tarvin Gray, Ralph Richmond Matthews, Leopold Singer.

Associate Members.—Allan Herbert Cowan, Griffith Vivian Davies, Francis Arthur Flinn, Ralph Wood Smith.

Transference to Associate Member.—Leonard Ogilvie Dalton.

Students.—Salim Daniel, George William Ford.

Associates.—John Henry Charles William Hopwood.

The Chairman stated that the President, Sir Thomas Holland, had been present at a very busy Council meeting that afternoon, and had hoped to have taken the Chair that evening for the greater part of the meeting. He had, however, been called away to attend another official meeting, and, rather than have any interruption of the business, he had asked him to take his place in the Chair.

The following paper was then read :—

The Conditions Governing the Occurrence of Oil in Burma.

By L. DUDLEY STAMP, B.A., D.Sc.(London), A.K.C., F.G.S., F.R.G.S. (Associate Member).

I. INTRODUCTION.

It is proposed to devote the present occasion to a consideration of the conditions governing the occurrence of oil in Burma. Next to coal, mineral oil is the most important of the mineral products of India, whilst the bulk of India's total comes from Burma. No apology is therefore needed for the subject matter. The present paper was written in outline over three years ago, when the writer was actively engaged in the oilfields of Burma as a geologist to one of the Oil Companies. It was written for personal satisfaction, rather than for publication. With one exception the writer had

visited and studied all the producing fields of Burma and the paper summarised his own ideas as to the conditions under which the oil-bearing beds were laid down. The paper has had the advantage of three years' consideration and has been amended accordingly.

It has a twofold object. In the first place it is intended to give a summary of the present state of knowledge concerning the geology and natural conditions affecting the Burmese oilfields. It is now nearly fifteen years since the publication of Dr. E. H. Pascoe's well-known memoir[1] and progress in the meantime has been considerable, thanks especially to the work of Vredenburg, Cotter and Murray Stuart. In the second place it is hoped that this review of field conditions over one well-marked region may afford at least some useful contribution towards that most elusive of problems, the origin of oil. In addition, certain somewhat neglected aspects of oil geology have been emphasised.

Many of the investigations on which this paper is based were carried out whilst the writer was in the service of Messrs. The Indo-Burma Petroleum Co., Ltd., and he is indebted to their managing agents, Messrs. Steel Bros. & Co., Ltd., for permission to publish this summary. The work has been supplemented by surveys carried out for Messrs. The Yomah Oil Co. (1920), Ltd., and, during the last three years, by research carried out under the auspices of the University of Rangoon.

II. An Outline of the Geology of Burma.

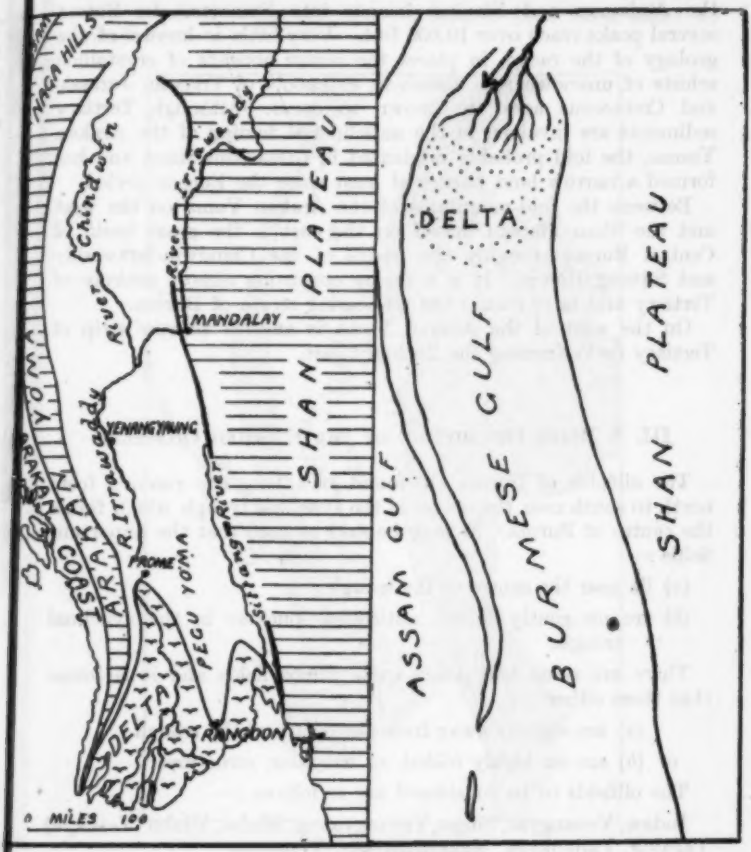
The general geology of Burma is relatively simple and controls the topography to such a marked extent that the natural geographical and geological units in the country closely correspond.

The whole of the east of the country, including the Shan States and the southward extension of Burma, known as Tenasserim, is formed of a massif of old hard rocks. The beds vary in age from Pre-Cambrian to Jurassic (Liassic) and the whole area has probably been land since the latter part of the Mesozoic. The massif forms a plateau with an average elevation, in the Shan States, of over 3000 feet. The only rocks younger than Jurassic present in the area are certain late Pliocene or Pleistocene deposits which are found in old lake basins. The latter are of some interest to the petroleum world since the infilling deposits include the oil-shales which are at present receiving investigation.[2] The western

[1] E. H. Pascoe, "The Oil Fields of Burma." *Mem. Geol. Surv. Ind.*, **40**. Pt. I., 1912.

[2] J. W. Gregory, "The Oil Shales of Southern Burma." *Geol. Mag.*, **60**, 1923, pp. 152–9. R. N. Crozier, "A New Development in the Treatment of Oil-Shale." *Mining Mag.*, **29**, 1923, pp. 265–9.

boundary of the Shan Plateau massif for many hundreds of miles forms a remarkably straight line running roughly north and south and giving rise to a marked surface feature. Along this line the



FIGS. 1 AND 2.
(From *Geol. Mag.*, 1922, p. 483.)

Tertiary rocks dip sharply away from the old massif, though the actual junction is rarely visible.

In the west of Burma the dominating feature is a great range of fold mountains. The range is complex and broad in the north

where it comprises the Naga, Chin and Lushai Hills, but narrows southward as the Arakan Yomas. Actually it terminates in Cape Negrais, but structurally the same fold continues through the Andaman and Nicobar Islands into Sumatra. In Burma several peaks reach over 10,000 feet. Very little is known of the geology of the range, in places the centre consists of crystalline schists of unknown age, elsewhere sediments of Triassic, Jurassic and Cretaceous ages are known to occur. Although Tertiary sediments are involved in the anticlinorial folding of the Arakan Yomas, the fold probably originated in Cretaceous times and has formed a narrow land barrier at least since the Eocene period.

Between the fold-mountains of the Arakan Yoma on the west and the Shan Plateau massif on the east is the great basin of Central Burma—roughly the basins of the Chindwin-Irrawaddy and Sittang Rivers. It is a region consisting almost entirely of Tertiary and later rocks—the oil-bearing strata of Burma.

On the west of the Arakan Yoma is another narrow strip of Tertiary rocks forming the Arakan Coast.

III. A Brief Description of the Existing Oilfields.

The oilfields of Burma are found as a long line running from north to south near the centre of the synclinal trough which forms the centre of Burma. It may be said at once that the important fields :—

(*a*) lie near the centre of the trough ;

(*b*) are on gently folded anticlines—puckers in the synclinal trough.

There are some half dozen quite minor fields and it is found that these either

(*a*) are slightly away from the centre of the trough ;

or (*b*) are on highly folded, or irregular, structures.

The oilfields to be considered are as follows :—

Indaw, Yenangyat, Singu, Yenangyaung, Minbu, Minbu (Yethaya) Tagaing, Padaukpin, Ngahlaingdwin, Yenanma.

1. *Indaw.*—The Indaw Field was unknown when Pascoe wrote his memoir. It was discovered rather over a dozen years ago by the geologists of the Indo-Burma Petroleum Co., Ltd., and production is first recorded officially for 1918. Structurally it is a fine, gently folded open dome and the field has great possibilities, since production up to the present has been from shallow sands. Deep testing is

being carried out, but so far has been unsuccessful, due to drilling difficulties and heavy gas. Indaw is situated in the wet zone of Upper Burma, north of the Dry Belt, and health conditions have caused much trouble, but active measures have been taken to combat fever.

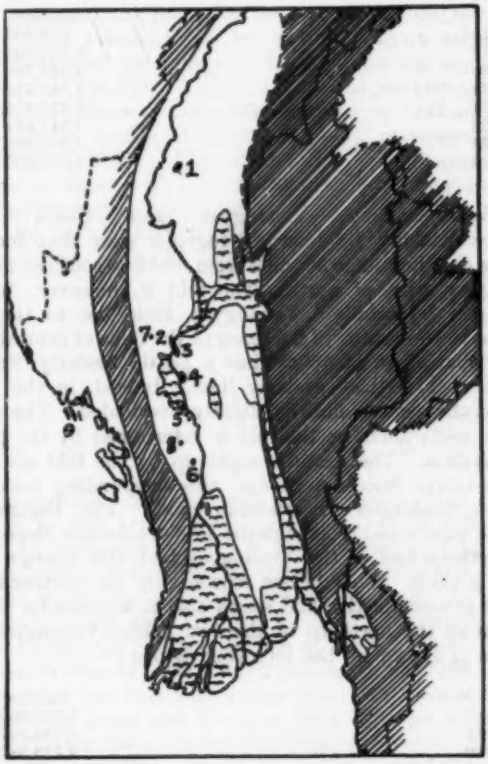


FIG. 3.

MAP SHOWING POSITION OF OILFIELDS.

The numbers correspond to the descriptions printed.

The company has followed the policy of steady development; the oil is sent by pipe line and refined at Pantha (22 miles distant) on the River Chindwin from whence it is sent down the river and supplies the local markets of Upper Burma. As will be explained

in a later section the petroliferous rocks of the great oilfields of Yenangyat-Singu and Yenangyaung pass northwards into barren, freshwater strata and the oil-bearing rocks of Indaw are probably much older than in other parts of Burma. The production at Indaw is shown in the annexed figures :—

	Gallons.
1918	473,800
1919	1,085,030
1920	1,022,766
1921	1,162,782
1922	1,210,914
1923	1,311,664
1924	1,474,898
1925	1,385,977

2-3. *Yenangyat-Singu.*—Yenangyat and Singu should, geologically speaking, be described together since they form part of one long anticline some 30 miles from north to south and striking a few degrees west of north. The fold is, however, breached by the River Irrawaddy; Yenangyat Field lies to the north, Singu Field to the south. Like many of the folds of central Burma the Yenangyat-Singu structure has a gentle westerly limb and a steep, almost vertical, easterly limb. Indeed, in the case of Yenangyat the eastern limb is slightly overfolded. The position of the two main fields on the fold is determined by the presence of crest-maxima. The rocks brought up by the fold are Peguan (Oligocene-Lower Miocene) in age, the surrounding rocks being the barren freshwater Irrawaddian sands. The Peguan rocks themselves pass steadily northward into freshwater deposits and at the northern end of the Yenangyat fold this change may be seen taking place. This is one reason why the northern end of the fold is non-productive and seems also to account for the rapid exhaustion of the northern of the two fields—Yenangyat. This exhaustion is shown by the following figures :—

	Gallons.
1917	6,700,000
1918	4,739,587
1919	4,123,387
1920	3,176,231
1921	2,510,533
1922	2,413,416
1923	1,700,035
1924	1,594,517
1925	1,562,444

The fold has been more extensively denuded at Yenangyat than at Singu and many of the productive sands of Singu outcrop

at Yenangyat. This is another reason for the poverty of Yenangyat when compared with Singu. Singu, on the other hand, has still great reserves and its production is likely to increase. A promising area lies in the bed of the Irrawaddy between the two existing fields and steps are being taken to reclaim a portion of this area and develop it. A shallow portion of the river is being shut off by a rubble wall, and drilling is to be carried out on the land so reclaimed. This scheme is known as the Lanywa scheme since the wall starts near the village of Lanywa, on the opposite side of the River to the Singu Field. The recent production of Singu is shown in the following table, the decrease in 1922 and 1923 is to be attributed mainly to labour troubles, particularly to the great strike in 1923. The figures may not appear very encouraging to those who look for spectacular jumps in production in British-owned fields, but they are consistent with the policy of the steady and truly scientific exploitation which is the strong feature of British oil interests the world over.

	Gallons.
1918	61,035,982
1919	93,626,506
1920	95,256,753
1921	104,167,749
1922	92,107,998
1923	87,476,474
1924	79,938,430
1925	95,262,519

4. *Yenangyaung.*—Yenangyaung has been so often described that it will be but briefly mentioned here. It is a fine gentle dome, slightly elongated in a NNW–SSE direction. It is situated right in the middle of the Tertiary trough of Burma and one point to be noted is the fine gathering ground for many miles round. The oil again comes from Peguan Rocks. Considering its size Yenangyaung can lay claim to be one of the wonder-fields of the world, the production of 3,000,000,000 gallons since 1900 having come from an area of just over one square mile. Two portions of the field, named the Beme and Twingon reserves, were set aside by Government for the use of the hereditary native owners (Twinzayos). Though some oil is still obtained by native hand-dug wells, the Twinzayos have sold nearly all their well-sites to the big companies and it is in these reserves that competition has been and still is so extraordinarily keen. The minimum distance between well sites is 60 feet; the prices demanded by the Twinzayos for a site has risen steadily from less than 50 to 50,000 rupees; there are now scarcely any available sites of value remaining. Outside the reserves—in the preserves of the Burmah Oil Co.—development

has been steadier and increase in the number of wells in the area seems likely to maintain production for some years to come if it is found wise on other grounds to do so. More recently oil has been struck at depths of over 3000 ft. in the southern portion of the field, more than a mile from the main producing area.

	Gallons.
1918	203,638,043
1919	190,322,077
1920	176,285,048
1921	184,420,141
1922	179,741,493
1923	175,158,721
1924	181,636,739
1925	160,027,885

5. *Minbu.*—Minbu, like Yenangyat-Singu, is another long fold of Peguan rocks but in this case is not closed to the south. Again there is a comparatively gentle western limb and an almost vertical eastern limb. Minbu still figures in the text-books as what it was hoped it might be. As an oilfield it never has been, and never will be, really important. A large part of the Peguan rocks exposed consists of a comparatively deep water shale, incapable of carrying oil. The upper sandy group, which is petroliferous, has been removed by denudation over most of the area. The existing production comes from four areas :—

(1) From the upper beds in the northerly pitching northern nose of the main fold, north of Minbu town.

(2–3) From two subsidiary dome structures developed in the midst of the main fold and where petroliferous sands at a much lower horizon are reached. These two structures are usually called the Palanyon and Yethaya fields.

(4) From lower sandy beds of a subsidiary northerly pitching nose at the southern end of the main fold (Tagaing or Minhla field).[3]

In both the first and fourth cases the oil has accumulated on a sort of terrace resulting from a change in pitch. Many of the Minbu wells are still yielding a few gallons a day although they only reach to a depth of two or three hundred feet and have been pumped continuously for as many as fourteen years. Yethaya and Palanyon are now the most steady producers. Tagaing has never paid its way.

[3] This field should be entirely separated from Minbu. See footnote in the discussion.

Minbu, Palanyon and Yethaya.[4]	Gallons.	Tagaing (or Minhla Field).	Gallons.
1914	1,683,190	1914	22,836
1915	2,316,207	1915	25,920
1916	2,043,542	1916	35,000
1917	3,468,382	1917	30,000
1918	4,826,735	1918	63,000
1919	4,423,361	1919 .. .	113,784
1920	3,835,198	1920	91,329
1921	3,706,831	1921	66,372
1922	3,940,416	Later figures not available.	
1923	3,915,140		
1924	3,829,044		
1925	3,248,566		

6. *Padaukpin.*—Coming southwards, the Peguan rocks, as a whole, become more argillaceous and probably of deeper water type. The highest beds are more mixed and capable of carrying oil, whilst much lower in the sequence are sandy groups, locally petroliferous. One of these lower sandy groups is exposed in the gentle, oval shaped dome of Padaukpin. Whilst the structure is good, it is doubtful whether the petroliferous strata attain any considerable thickness. Since 1920 the field has been developed by the Indo-Burma Oilfields (1920), Ltd. Pumping started on March 7th, 1922, and the production as recorded by the company has been :—

	Barrels.[5]
1922	13,524
1923	16,079
1924	15,208
1925	14,000(approx.)
1926	17,000(est'm'd)

7. *Ngahlaingdwin.*—This field, which is really still in the exploration stage, is situated at the southern end of a long narrow fold of Peguan Rocks. Further north is the Pauk Field, which has yielded a small quantity of oil. Ngahlaingdwin is being exploited by the British Burma Petroleum and the Indo-Burma Petroleum Companies. The oil appears to come from the lower beds of the Peguan, and the structure belongs to the class of narrow folds situated to the west of the central line of the Tertiary trough. The drilling has not, so far, been successful, and operations are suspended.

8. *Yenanma.*—Yenanma is a remarkable little field which stands alone amongst the Burmese fields. It seems, on superficial examination, to consist of a pocket of oil-bearing sands situated

[4] These fields all lie in the Minbu District and the productions are not separately stated in Government statistics.

[5] This is well head production and hence greater than the production on which royalty is paid) shown in Government returns.

in the midst of a group of laminated clays and sands forming a homocline (or monocline) with a steady easterly dip of 20° to 25°. However, as explained by Murray Stuart in this Journal, Vol. XI, No. 52, October, 1925, pp. 481-485, it is believed by some that these beds are thrust westwards over folded rocks of similar or rather earlier age and that the oil comes from a hidden anticline. It should be mentioned, however, that this conception of the structure is not shared by many geologists who know Burma thoroughly well. Following along the outcrop seepages may be traced for a distance of some 40 miles on two distinct horizons, one near the base of the Peguan and the other some 2000 or 3000 ft. lower in the higher part of the Eocene. There may, therefore, be other oil-pockets below the monocline, but there would seem to be no indication whereby they can be located. Yenanma is exploited by the Indo-Burma Oilfields (1920), Ltd., and the production has been since pumping was commenced on January 12th, 1922:—

	Barrels.[6]
1922	54,295
1923	36,649
1924	33,854
1925	27,000(approx.)
1926	17,000(est'm'd)

9. *Arakan Coast.*—Several of the closely folded anticlines of the Arakan Coast are petroliferous, but the deposits appear to belong to a separate basin of sedimentation. As the writer has only casually examined this region, these occurrences will not be considered here. The licensees at present are all natives and the oil is won by native methods, production is declining and does not now exceed 50,000 gallons annually (in 1924 it was 21,714 gallons).

IV. The Stratigraphy of the Tertiary Rocks of Burma.

The Tertiary rocks of central Burma fall into three main divisions:—

Irrawaddian (Mio-Pliocene).
Peguan (Oligo-Miocene).
Eocene.

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[6] Well head production as recorded by the company. The Government returns for the Thayetmyo District, including both Padaukpin and Yenanma as well as a few thousand gallons from Tagaing, are as follows:—

	Gallons.
1922	2,319,835
1923	1,818,584
1924	1,717,653
1925	1,320,009

All horizons from the middle of the Eocene to the top of the Peguan may be petroliferous, and the oil in existing fields is obtained from all horizons from the base to the top of the Peguan and probably from the higher Eocene. It is accordingly a matter of no little practical importance to attempt to trace the connexion between the petroliferous and stratigraphical horizons.

To do so, it is simplest to consider the conditions under which the beds were laid down. In early Tertiary times one may picture Burma as a broad gulf of the sea with the Shan Plateau forming the land mass on the east and the central ridge of the Arakan Yomas forming a narrow strip of land on the west.[7] The gulf would be broader than appears at the present day owing to the extensive lateral compression and folding which has since taken place. The gulf was probably open to the south, but into the northern end there embouched one or more great rivers. Possibly the Tibetan course of the Brahmaputra is a remnant of this river, at a later stage rivers of which the Chindwin and the Irrawaddy are the modern descendants took its place. *The whole history of the Tertiary period may be summed up as the history of the infilling of the Burmese gulf by river-borne sediment from the north and by marine sediments in the south.* On the whole, therefore, there has been a spread of continental deposits from the north, pushing the marine waters further and further to the south. This process is still going on, for year by year the Delta of the Irrawaddy encroaches on the shallow Gulf of Martaban. The gradual infilling of the trough has, however, been interrupted at intervals by lateral folding movements. These movements resulted in the gradual uplift of the Arakan Yomas, and at a later stage of the Pegu Yomas and other folds. Each movement of folding, however, resulted in a temporary increase in depth of the centre of the trough and a consequent return northwards of marine conditions. *Thus it is found that the gradual southward retreat of the sea was interrupted by temporary northward movements which have left their mark as wedges of marine strata tailing out northwards.*

These changes have a very definite significance in the search for oil. It is found that the freshwater sands (*e.g.*, Irrawaddian) and freshwater clays, with remains of crocodiles, turtles and mammals, are entirely devoid of oil; the deeper marine water clays are equally devoid of oil. *All the petroliferous horizons are definitely associated with intermediate conditions.* In passing it

[7] There are some geologists, including Murray Stuart, who prefer to refer to the Arakan Yoma strip as an island, since the fluviatile Tertiary sands in the extreme north of Burma seem to be continuous with those of Upper Assam.

may be noted that the Tertiary coals of Burma are also associated with intermediate conditions, but occur in deposits indicating closer association with fresh water than does the oil.[8]

The old idea that the oil-bearing beds of Burma occupied a definite stratigraphical horizon is wholly fallacious, and the long-standing controversy as to whether this petroliferous horizon was older or newer than the Kama Clay is equally futile. Once it has been realized that the petroliferous deposits of Burma change their horizon in this way, it is surprising how remarkably well the lithological and palæontological evidence fit together.

It is useless to pretend that geologists in Burma have had, or even yet have, an easy task. It is always possible to "map" lithological horizons, but what actually happens to the petroliferous horizons has been learnt in most cases by the very expensive method of unsuccessful drilling. Burma abounds with examples of promising structures which have yielded nothing. There can be little doubt that the failures have been due to the oncoming of more marine conditions experienced in any one horizon as one proceeds southwards. Beds on the same horizon as the best sands of Yenangyaung are barren marine clays at Minbu and, judging by the present succession of failures, at Ondwe. Yet these localities are only some 20 miles further south.

It will now be advisable to outline the geology.

Eocene.

Eocene beds are exposed mainly on the western side of the Tertiary trough where they form the foot hills of the Arakan Yomas. The general succession in the centre (intermediate type) is as follows:—

Yaw Shales.
Pondaung Sandstones.
Tabyin Clays.
Tilin Sandstones.
Laungshe Shales.
Paung-gyi Conglomerate.

[8] There seems to be no doubt of this, although it is in opposition to the general conclusions of Stuart, recently expressed in this Journal (Vol. XII, No. 56, June, 1926, p. 320) that "the seam (of coal) will pass laterally into either oil-shale or oil deposits when traced towards the direction from which the material was originally transported." The issue is complicated by the oil measures being best developed in the centre of the trough, the coal seams having been studied along its western margin. However, a decisive factor is the association of shallow water marine fossils with the oil measures, but never with the coal seams, where the fossils are mainly leaves.

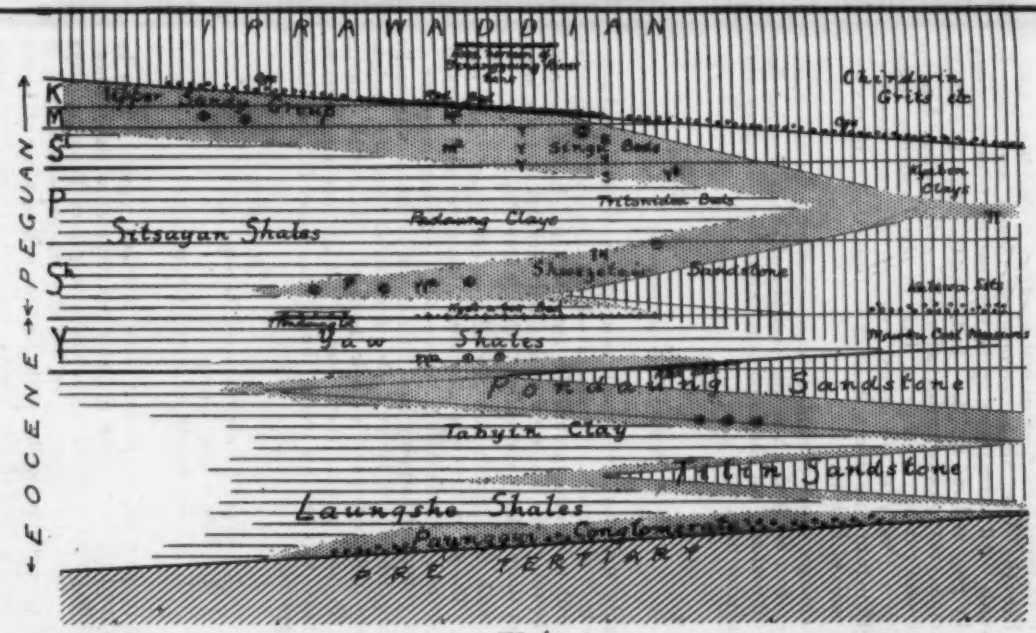


FIG. 4.

DIAGRAMMATIC SECTION FROM SOUTH TO NORTH THROUGH THE TERTIARY TROUGH OF BURMA.

Lithology:

Vertical lines = freshwater beds; nearly all with silicified fossil wood and occasional remains of mammals, crocodiles and turtles. Mainly coarse sands.

Dotted = marine and estuarine beds, mainly sandy.

Horizontal lines = marine and brackish water beds, predominantly clayey.

Palæontology:

Y = Yaw Stage; Sh = Shwezetaw Stage; P = Padaung Stage; Si = Singu Stage; M = Migyaungye Stage; K = Kama Stage.

Oil Geology:

? I = Probable oil horizon of Indaw.
Yt = Oil horizon Yenangyat.
S = Oil horizons of Singu.
Y = Oil horizons of Yenangyaung.
M¹ = Oil horizon of Minbu (N).
M² = Oil horizons of Minbu (Yethaya and Tagaing).
P = Oil horizon of Padaukpin.
? Ya = Oil horizon of Yenanma (alternative).
? N = Probable oil horizon of Ngahlaingdwin.
⊙ = Oil horizons not commercially exploited.

The sandy beds, like the Tilin Sandstones and the Pondaung Sandstones, become attenuated and disappear southwards; marine clays like the Yaw Shales become attenuated and disappear northwards. All sediments may be replaced by freshwater clays —usually grey and red mottled—in the north. The Yaw Shales, for example, are typically marine as far north as the Lower Chindwin District (see Stamp, Geology of Part of the Pondaung Range, *Trans. Min. Geol. Inst., India*, vol. xvii., pp. 161–180), but in the Upper Chindwin pass into a series of coal measures with the well known coals of Kalewa.

The changes are represented diagrammatically in the accompanying ideal section, where the position of the oil-bearing beds is also indicated. All the important fields, however, draw their oil from later beds.

Peguan-Irrawaddian.

Roughly speaking the Peguan corresponds to the post-Eocene marine beds of Burma. Over most of the country it is overlain by a great freshwater group, the Irrawaddian. In the extreme north, however, the whole succession is freshwater and the lower part has there often been called "Freshwater Pegu."

It is with the Peguan that the oil geologist is especially concerned. The group reaches a measured thickness of over 14,000 ft. in places and so subdivision is essential. For the purposes of detailed geological mapping local lithological horizons can usually be distinguished, but it must be remembered that the various beds are not constant in their horizon. About the middle of the Peguan period, there was a marked marine invasion northwards, and for this reason the Peguan rocks fall into three broad groups:—

3. Upper Sandy or mixed Group.
2. Middle Clay Group.
1. Lower Sandy or mixed Group.

For the purpose of comparison with previous papers it may be noted that the lower group includes the Shwezetaw Sandstones; the middle group is the Sitsayan shales (south) or Padaung Clays (north); whilst the upper group includes the exposed Peguan of most of the oilfields together with the Prome Sandstones of Lower Burma. A thin band of clay intercalated in the Prome Sandstones is the Kama Clay which, partly owing to confusion with the

Sitsayan Shales, has assumed an altogether unwarranted importance in the literature of Burmese geology.[9]

The remarkable way in which the lithological beds change their horizon has been demonstrated not only by field mapping but by the separation of a number of "stages" on a Palæontological basis. The stages are as follows[10]:—

5. Kama Stage.
4. Migyaungye Stage.
3. Singu Stage.
2. Padaung Stage.
1. Shwezetaw Stage with Kyet-u-bok Bed at the base.

The exact status of the "Akauktaung Stage" said to exist above the Kama Stage in Lower Burma is at present uncertain.

The annexed diagrammatic section (Fig. 4) illustrates the relationship between the palæontological stages and the lithological stages far more clearly than pages of description would do. The interesting point to notice is the way in which the upper petroliferous horizons pass into newer and newer beds as one moves from north to south. It is obvious that only a careful consideration of both the lithological and Palæontological evidence will give a clue to the position of the petroliferous horizons in any given locality.

It may be noted in passing that the Peguan rocks range in age from the base of the Oligocene to about the middle of the Miocene; the Irrawaddian probably from the mid-Miocene onwards. The Irrawaddian consists for the most part of coarse, false bedded sands.

In view of the numerous correlations which have been proposed for the Peguan rocks of Burma, it is unlikely that the present writer's general conclusions will be immediately accepted by all workers in Burma. Accordingly, some of the detailed evidence

[9] The Kama Clay is virtually a myth. It is a clayey band—one amongst hundreds—in the predominantly sandy part of the Upper Peguan. It attracted the attention of Theobald (1870–74) by its well preserved fossils, afterwards described by Noetling. The band was wrongly located as now entirely hidden by alluvium by Murray Stuart (1910), but correctly re-located by Vredenburg (1921). The writer located it, after considerable search, in 1922. The sooner the Kama Clay is forgotten by oil geologists, the better.

[10] With the exception of the insertion of 4 and the elimination of the Pyalo Stage, the stages are the same as adopted by Vredenburg. Vredenburg established his horizons by detailed palæontological studies, the writer by careful mapping and collecting in the field. It is unfortunate that most of Vredenburg's material came from the Peguan members of the oilfields and not from the main Peguan outcrops of the west; but this need not invalidate his studies.

has been set out in the form of an appendix, and geologists are at liberty to test the conclusions in the field.

V.—The Conditions of Deposition of the Oil-bearing Beds.

The rapid alternation of beds of impervious clay and porous sands almost precludes the possibility of extensive vertical migration of oil. Indeed, all the evidence which the writer has seen tends to support the view that the oil of Burma originated in the beds in which it is now found and that only lateral

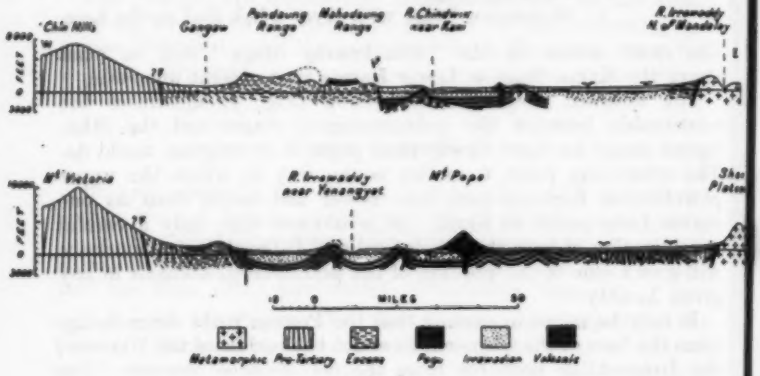


FIG. 5.
SECTIONS.

migration has been important. All along the outcrop of the Yenanma and Upper Eocene petroliferous horizons little lens shaped streaks—from ⅛ in. to several feet in thickness—of sand saturated with oil may be found entirely surrounded by clay. It seems impossible that the oil could have got into such a position from outside. Similarly, in the great fields conditions are against vertical migration.

Presuming, then, that the oil originated where it is now found, certain definite conclusions may be formed :—

1. Oil is never found in beds of definitely fresh water or æolian origin such as the Irrawaddian.
2. Oil is never found in beds originating in deeper marine waters, "deeper" being here used in a strictly comparative sense. The Sitsayan shales—rubby, or concretionary shales, are a typical example, but there are beds which, from their laminated nature, might be thought capable of bearing oil,

but which do not. It has been found that these beds are characterised by what is sometimes called a "*Pleurotoma*-fauna" and which is generally acknowledged to indicate deeper water than certain other mixed lamellibranch-gastropod faunas. The petroleum geologist is often apt to scoff at the use of fossils. The palæontologists are to blame to some extent for over-emphasising details of nomenclature. The oil geologist in Burma can learn a great deal of importance from the facies of an assemblage of fossils without knowing the name of a single one.

3. Oil is always found in strata in which the majority of the fossils are marine, but of shallow water type. Traced along the strike into areas where the conditions more approached the fluviomarine or freshwater, the same beds often carry seams of coal. In all such cases oil is always found under more marine conditions than coal.

Whilst, then, there is a very definite connexion between the occurrence of oil and the conditions as indicated by fossils, the lithology and tectonics, as in other parts of the world, have controlled the accumulation of large quantities. Lithologically, oil in Burma is found in beds characterised by a rapid alternation of sands, and shales, whether on a very small scale (say in layers of $\frac{1}{8}$ in.) or on a large scale. Crystals of gypsum are common, but are more characteristic of beds above the oil-horizons and many of the localities where gypsum is most abundant are non-petroliferous.

It has already been pointed out that during the deposition of the oil-bearing beds, central Burma was occupied by a gulf into which fresh waters poured from the north. It is now possible to say that the oil-bearing rocks of Burma were deposited on the seaward side of a delta and that the oil originated under such conditions of admixture of fresh and salt water as permitted the existence of a definitely marine though shallow water fauna. Seawards (*Pleurotoma* Shale facies) oil is not found; landwards or riverwards its place seems to be taken by coal; under definitely fluviatile conditions the vegetable remains have been silicified and fossil wood is very common.

The Connexion between Coal and Oil.

During the course of his investigations the writer was much impressed by the constant passage of oil-bearing beds into coal-bearing beds, and for long was strongly inclined to believe that both were of vegetable origin but that oil originated under more marine conditions than did the coal. However, coal would

FIG. 6.
TYPICAL BANDED ROCKS.

naturally be expected under conditions such as have been described, and one would be surprised to find coal-seams completely absent. When one considers other parts of the world, one is strongly tempted to conclude that the association is accidental and that the association is very apt to draw one's attention from the really important conclusions, *viz.*, that for the formation of oil one must have a certain necessary concentration of salts in the water. Such concentration may be found :—

1. On the seaward side of a delta (as in Burma).
2. In a land-locked lake or sea, or a lagoon where connexion with the sea is almost severed.

The importance of the salt-concentration may be direct, *i.e.*, catalytic in its influence on the conversion of the mother-substance into oil ; but more likely indirect in encouraging the development of bacteria believed to be required for the change.

Unfortunately, the occurrence of coal and oil in the same bed argues but little for either the vegetable or animal origin of the oil. One may conclude either :—

1. Oil is of vegetable origin, but has accumulated under the influence of a greater concentration of salts in the water than existed where coal was being formed ; or
2. Oil is not of vegetable origin, since all the original vegetable matter in the particular bed has been changed to coal, as is evidenced by the occurrence of coal but a short distance away.

Moreover, the association of coal and oil seems to be more or less restricted to those regions in which oil was formed to the seaward side of a delta ; in those cases where the necessary concentration of salts in the water was attained in a land-locked lagoon any deposits of coal are entirely wanting.

If it is of any comfort to the fish-origin enthusiasts, bone-beds with fish remains are very commonly associated with oil-bearing beds in Burma from the Eocene to the top of the Peguan. Here again, however, this association may be accidental, since one would expect the mortality among fish to be high under such changing or passage conditions of salinity as postulated above.

Since the above paragraphs were written several papers dealing with the origin of oil in Burma, from the pen of Murray Stuart, have appeared. He insists, particularly, on the wood of Dipterocarps found in a silicified condition so abundantly in the Tertiary of Burma, having supplied the necessary organic material. If the chemists are satisfied as to the possibility of this material as the mother-substance of the oil, there seems no geological reason against the suggestion. Curiously enough, however, Murray

Stuart insists on the importance of the forests which he believes were growing on the Arakan Yoma Island. He seems to imagine all the oil extracted in Peguan time, before the trunks were silicified and distributed through the Irrawaddian sands. There are several objections to this :—

(1) There is evidence that little, if any, of the Tertiary sediments were derived from the narrow strip of land forming the Arakan Yoma. All the evidence points to derivation of sediment from the north.

(2) The huge logs of silicified wood, entirely unrolled and sometimes over 100 feet in length, which occur in the Irrawaddian were silicified in situ where they are now found. It seems impossible to conceive any mechanism whereby the oil from them could have got into beds 10,000 feet below the horizon where the silicified trunks are found.

But Murray Stuart's idea will hold, provided he is willing to admit derivation of his material from the north. There, in beds of the same age as the oil-bearing beds further south, vast quantities of fossil wood are found.

VI.—Conclusion.

In preparing this paper the writer has availed himself of all published matter known to him, of which the bulk is the work of the Geological Survey of India. Pascoe's Memoir contains an exhaustive bibliography up to 1911; most of the important references up to 1922 are included in Stamp's "Outline of the Tertiary Geology of Burma" (*Geol. Mag.*, Vol. LIX., 1922, pp. 481–501). There are some corrections and additions to that paper in Stamp's "Seasonal Rhythm in the Tertiary Sediments of Burma" (*Geol. Mag.*, Vol. LXII., 1925, pp. 515–528). The writer has been placed in a slightly difficult position in having had through his hands all the geological files of two well-known companies in Burma. Every effort has been made to exclude all this private and unpublished information, but it is obvious, from the publication of the present paper, that the writer finds his views corroborated therein.

Appendix.

Some of the detailed Palæontological and Stratigraphical work on which the general conclusions are based.

The Palæontology of the Marine Peguan of Burma.

In dealing with the numerous collections of fossils which were made during the course of this investigation, it was found con-

venient to determine their relationships by comparing them with what may be termed the four standard faunas of the marine Peguan. These are the faunas from known and localised horizons at Yenangyat, Singu, Minbu and Kama. It is important to emphasise that nothing was taken for granted concerning the relative ages of these "standard faunas." As the work progressed, however, it became increasingly apparent that the order adopted by Vredenburg was the correct one. Take, for example, the sequence of faunas observed in the neighbourhood of Sinbaungwe. High up in the Peguan, both east of the town and further north near Thabutkyaw, one finds the typical Kama fauna. Some 2800 feet from the top—a little over a mile east of the town—one finds a rich fauna intermediate between that of Singu and Kama. On the opposite side of the river, lower in the sequence, whole series of faunas are unmistakable in their similarity to the Singu fauna. Still lower in the sequence, in the hills opposite Sinbaungwe and at Chaungtha, near the base of the exposed section, have been found some of the most distinctive forms of the Yenangyat fauna. This case is but one of the many now available which afford actual field evidence for the sequence of faunas in the Burmese Peguan. Such being the result of carefully collected field evidence, the following general account of the palæontology is offered.

Thanks to the extensive and careful work of Vredenburg on the Siphonostomata, one can now with confidence use this group in correlation work. It must be stated that in first working out the results embodied in the present paper, the writer took into account all the fossils, including the Holostomata and the Lamellibranchiata. They afforded evidence which entirely corroborated that of the Siphonostomata, but it was necessary to use a considerable number of provisional names for undescribed species, and it seems very unwise at the present time either to perpetuate some of the old and mistaken identifications or to introduce a number of new names without proper descriptions. For these reasons the following particulars deal mostly with the siphonostomatous gastropods.

The Standard Faunas of the Peguan of Burma.

I. *Yenangyat* (Noetling's Zone of *Paracyathus caeruleus*). This fauna occurs in a bed not far from the crest of the Yenangyat fold and about 4800 feet below the local top of the Peguan. It has been proved by actual mapping to be below the Singu fauna.

Surcula (*Pleurofusia*) *feddeni* Noet. sec. Vred.
Pleurotoma (*Hemipleurotoma*) *yenanensis* Noet.
Conus (*Lithoconus*) *ineditus* Mich.
Conus (*Leptoconus*) *protofurvus* Noet.

Conus (*Conospira*) *galensis* Noet.
Merica (*Cancellaria*) *pseudocancellata* Noet.
Olivella minbuensis Vred.
Athleta (*Volutospina*) *jacobsi* Vred.
Clavilithes seminudus Noet.
Tritonidea martiniana Noet.
Cypraea (*Cypraeotrivia*) *oppenheimi* Vred.
Trivia noetlingi Vred.
Murex iravadicus var. *yenanensis* Vred.
Pirula condita Brongn.
Hindsia birmanica Vred.
Hindsia pardalis Noet.
Hindsia neastriatula Noet.
Ranella tubercularis Noet.
Lathyrus indicus Vred.
Turritella magnasperula Sacco sec. Vred.

II. *Minbu* (Noetling's Zone of *Cancellaria martiniana*). This fauna was obtained from a bed to the west of Minbu town and near the centre of the fold. It would therefore be about 3500 feet below the local top of the Peguan.

Terebra (*Subula*) *noetlingi* Vred.
Surcula (*Pleurofusia*) *feddeni* Noet.
Clavatula protonodifera Noet.
Drillia protointerrupta Noet.
Genotia iravadica Noet.
Conus (*Lithoconus*) *ineditus* Mich.
Conus (*Lithoconus*) *odengensis* var. *avaensis* Noet.
Olivella minbuensis Vred.
Athleta (*Volutospina*) *jacobsi* Vred.
Voluta ringens Noet.
Volvaria birmanica Noet.
Clavilithes seminudus Noet.
Lathyrus indicus Vred.
Siphonalia (*Kelletia*) *iravadica* Vred.
Cyrtochetus minbuensis Noet.
Tritonidea martiniana Noet.
Lacinia minbuensis Vred.
Murex (*Chicoreus*) *arakanensis* Noet.
Murex (*Muricantha*) *iravadicus* Vred.
Tritonium (*Lampusia*) *dubium* Noet.
Hindsia birmanica Vred.
Hindsia neastriatula Noet.
Hindsia pardalis Noet.
Ranella tubercularis Noet.

Cassidea birmanica Vred.
Pirula concinna Beyr. var.
Cypraea (*Cypraeotrivia*) *oppenheimi* Vred.
Turritella magnasperula Sacco sec. Vred.

III. *Singu.*—This fauna is to be found in a number of fossiliferous beds at varying distances of 1000 to 2400 feet from the local top of the Peguan.

Terebra quettensis Vred.
Clavatula protonodifera Noet.
Clavatula birmanica var. *singuensis* Vred.
Surcula (*Pleurofusia*) *feddeni* Noet.
Pleurotoma singuensis Vred.
Genotia iravadica Noet.
Genotia singuensis Vred.
Conus (*Lithoconus*) *ineditus* Mich.
Conus (*Lithoconus*) *odengensis* var. *avaensis* Noet.
Conus (*Leptoconus*) *protofurvus* Noet.
Conus (*Conospira*) *galensis* Noet.
Olivancillaria nebulosa var. *pupa* Sow.
Marginella singuensis Vred.
Athleta (*Volutospina*) *jacobsi* Vred.
Mitra singuensis Vred.
Clavilithes seminudus Noet.
Vasum basilicum Mich.
Melongena pseudobucephala Noet.
Melongena acanthina Dalton.
Melongena praeponderosa Vred.
Lacinia minbuensis Vred.
Tritonidea martiniana Noet.
Purpura singuensis Vred.
Persona reticulata var. *clathrata* d'Orb.
Cassidea birmanica Vred.
Cassideae chinophora var. *monilifera* Noet.
Pirula condita Brongn. var. *singuensis* Vred.
Cypraea singuensis Vred.
Turritella magnasperula Sacco.
Turritella angulata Sow. 1-ribbed form.
Vicarya verneuili d'Arch.

IV. *Kama.*—This fauna occurs at or near the junction of a band of soft sandstone and a band of clay, and may still be studied on the riverward slopes of the pagoda-crowned ridge, the first ridge to the south of the mouth of the Nade Chaung at Kama. The bed is 2500 feet below the local top of the Peguan. It is very

probable that the bed, or one very near it, formerly outcropped on the river bank itself "below Kama."

Terebra (*Myurella*) *protomyuros* Noet.
Terebra samaranga Martin.
Terebra protoduplicata Noet.
Surcula karenaica Noet.
Surcula (*Pleurofusia*) *scala* Noet.
Clavatula munga Noet.
Drillia kamaensis Vred.
Drillia cotteri Vred.
Drillia promensis Noet.
Drillia protocincta Noet.
Conus (*Leptoconus*) *yuleianus* Noet.
Conus (*Leptoconus*) *hanza* Noet.
Conus (*Leptoconus*) *bonneti* Cossm.
Conus (*Leptoconus*) *protofurvus* Noet.
Ringicula turrita Martin.
Oliva (*Strephona*) *australis* var. *indica* Vred.
Cryptospira birmanica Vred.
Eburna lutosa Lamk. var.
Ranella promensis Vred.
Ranella antiqua Vred.
Lathyrus (*Peristernia*) *gautama* Noet.
Hindsia neacolumbrina Noet.
Pirula promensis Vred.
Cassidaria echinophoria var. *promensis* Vred.
Rimella javana Martin.
Rimella promensis Vred.
Turritella angulata Sow. 1-ribbed form.
Turritella angulata Sow. 2-ribbed form.
Turritella leiopleurata Noet.
Turritella lyddekeri Noet.
Turritella noetlingi Vred.

The Palæontological Stages of the Peguan.

The marine Peguan is divided into :—

5.	Kama Stage.	MIOCENE
4.	Migyaungye Stage.	
3.	Singu Stage.	
2.	Padaung Stage.	OLIGOCENE
1.	Shwezetaw Stage.	
	Kyet-u-bok Horizon or Bed.	

The Kyet-u-bok Horizon or Bed.—This is a well-marked bed which may be traced for 50 or 60 miles in the west of the Thayetmyo and Minbu Districts, especially from Yenauma into the

Pyawbwe-Ngape area. Northwards it seems to be continuous with Cotter's G Bed[11] and then with the *Velates* Bed, which occurs at the top of the Yaw Stage at Dudaw Taung and towards Ngahlaingdwin. It is usually conglomeratic and some of the contained fossils are rolled; moreover, it passes up quite naturally into the overlying beds. For these reasons the writer regards it as the basal bed of the Peguan rather than the highest bed of the Eocene. Truly the majority of its fossils show Eocene affinities, but basal beds frequently have many of the fossils of the underlying beds, and it is the incoming new elements of the fauna which must determine the age of the bed. Unfortunately the fauna of the overlying Shwezetaw Stage is very little known, and the percentage of Pegu forms in the Kyet-u-bok Bed cannot yet be determined. The bed itself—usually a calcareous, conglomeratic sandstone or a sandy limestone—is crowded with :—

Nummulites yawensis Cotter (=*N. beaumonti* ?, fide Dalton).
Orthophragmina omphalus Fritsch.
Gypsina globulus Reuss.
Operculina cf. *canalifera* d'Orb.

Fairly numerous gastropods and lamellibranchs occur.

The Shwezetaw Stage.—This stage is represented by sands and sandstones in the Lower Chindwin, Pakokku and northern parts of the Minbu Districts. In the first named District and northwards from there the beds are fluviatile, at least in the main. From the Minbu District northwards coal seams are frequently associated with this stage. In the Pyawbwe-Ngape area of Western Minbu shaley beds set in at the base of the stage and rapidly replace the sandy type of sediment, so that at Yenanma the stage consists of banded sediments predominantly shaley in character. According to Vredenburg[12] the following fossil is characteristic of the sandy facies :—

Ampullina (*Megatylotus*) *birmanica* Vred.

It has been recorded from such widely separated areas as near Ngape, Ngahlaingdwin, and Shinmadaung (north of Pakokku). No fauna from the shaley deeper water beds of Shwezetaw age has yet been described in detail[13]. One was collected from this horizon by the writer at Magyisan. Practically all the species seem new, though the facies of the fauna is like that of Dalabe, in that it is a

[11] Cotter, *Rec. Geol. Surv. Ind.*, 1912, **41**, Pt. IV., 221–239.
[12] Vredenburg, *Rec. Geol. Surv. Ind.*, 1921–2, **53**, Pt. IV., 359–369.
[13] Cotter has recorded the Yaw Stage *Corbula subexarata* from this horizon in the Ngape area, as well as *Venus aglourœ*, *Donax sp.*, and one or two others.

Pleurotoma-shale fauna. One form seems to be identical with the Eocene *Conus gracilispira*, whilst another is *Athleta jacobsi*, which is characteristic of the succeeding Padaung Stage.

Padaung Stage (Sitsayan Stage of Vredenburg).—This stage marked the greatest extent of the Pegu sea in Burma, and is represented by marine deposits as far north as the north of the Pakokku District. The sandy clays there pass southwards into the fossiliferous *Tellina* Clays of Ngahlaingdwin and into the Padaung Clays of the Pwaybwe-Ngape area. Southwards they merge into the great mass of the Sitsayan Shales, but only the central portion of the latter belongs to the Padaung Stage. The Padaung Stage includes the fossiliferous horizons (lower beds) of Yenangyat and the lower clayey group of the centre of the Minbu Anticline. The Yenangyat fauna (Noetling's "Zone of *Paracyathus caeruleus*," 4800 feet below the Irrawaddian) belongs to the Padaung Stage, whilst the Minbu fauna (Noetling's "Zone of *Cancellaria martiniana*") occurs near its upper limit. According to the Survey, the Dendrophyllia-Schizaster Beds of Yenangyat, Singu, Minbu, opposite Sinbaungwe, Kanhla, etc., occur at the junction of the Padaung Stages and Singu. The present investigation has tended to corroborate this suggestion, except that the "Dendrophyllia Bed" of the localities in Lower Burma is rather higher. Among the characteristic fossils of the Padaung Stage are:—

Surcula feddeni Noet.
Conus ineditus Mich.
Conus protofurvus Noet.
Olivella minbuensis Noet.
Athleta jacobsi Vred.
Tritonidea martiniana Noet.
Hindsia birmanica Vred.
Turritella magnasperula Sacco.
Arca bistrigata Noet.

The fauna, it may be noted, is closely allied to that of the succeeding Singu Stage, but the *absence* of such characteristic Singu forms as *Terebra quettensis* Vred., *Melongena pseudobucephala*, *Melongena acanthina* Dalton, *Melongena praeponderosa* Vred.[14], and *Turritella angulata* Sow.[15], should be carefully noted. The fauna from the top of the Padaung Clay at Pyawbwe (Western Minbu), which occurs in a sandy bed immediately above the mass of the clay, may be taken as the base of the overlying stage.

[14] Vredenburg, however, mentions this fossil as occurring at Minbu.
[15] Cotter records the many-ribbed form of this species from the Padaung Clay of Western Minbu, and too much reliance must not be placed on *Turritella*.

The Singu Stage.—This stage includes the exposed fossiliferous beds at Singu, the higher beds at Yenangyat, possibly the lower part of the exposed Peguan at Yenangyaung and the greater part of the upper group of the Minbu Anticline. A representative of the succeeding Migyaungye Stage is present at Yenangyaung as evidenced by the faunas recorded by Pascoe from Taung-hnit-lon and Natsin-Yo. It has already been stated that the Minbu fauna, which is found near the centre of the fold, belongs to the top of the Padaung Stage. The highest beds almost certainly belong to the Migyaungye Stage (including the *Arca* Bed of Pascoe). The mass of sediments between these two horizons must belong to the Singu Stage, but unfortunately there are but few fossils. At the southern end of the Minbu fold the Singu fauna has been recognised at Tagaing. Opposite Sinbaungwe there is a great thickness of sediments of Sitsayan Shale type and which merge southwards into the main mass of the Sitsayan Shales. Many beds there have yielded rich faunas absolutely typical of the Singu Stage. From there to Thayetmyo various localities situated on the Sitsayan Shales along the banks of the River—notably near Sinde—have yielded the Singu fauna. Leptanzeik, already claimed by Vredenburg as yielding a Singu fauna, is in this region. Immediately south of Thayetmyo itself the *Lepidocyclina* Sandstone (Padaung Stage) occurs in the upper part of the lower sandy group of the Pegu, whilst a Migyaungye fauna occurs in the lower beds of the upper sandy group. It would appear almost certain, therefore, that the greater part of the intervening Sitsayan Shales belong to the Singu Stage. The following may be regarded as the more typical Singu Stage fossils:—

Terebra quettensis Vred.
Surcula feddeni Noet.
Genotia iravadica Noet.
Conus odengensis var. *avaensis* Noet.
Conus ineditus Mich.
Olivancillaria nebulosa var. *pupa* Sow.
Athleta jacobsi Vred.
Melongena pseudobucephala Noet.
Melongena acanthina Dalton.
Melongena praeponderosa Vred.
Tritonidea martiniana Noet.
Cassidea echinophora var. *monilifera* Noet.
Pirula condita var. *singuensis* Vred.
Turritella magnasperula Sacco.
Turritella angulata 1-ribbed and 2-ribbed forms.
Vicarya verneuili d'Arch.

Leda birmanica Noet.
Meiocardia metavulgaris Noet.
Tellina grimesi Noet.

The Migyaungye Stage.—This stage has been separated to embrace a large number of faunas intermediate between the Singu and Kama. It was not found difficult to identify typical Singu or Kama faunas, but the differences between these two standard faunas are very great—much greater than between the other standard faunas—and the recognition of an intermediate Migyaungye Stage simplifies the classification considerably. Unless this is done, it becomes necessary to give a long list of fossils which appear in the higher part of the Singu Stage, and also to give another long list of survivals in the lower part of Kama Stage. It is admitted that the fauna of the Migyaungye Stage is essentially a mixture of that of the Singu and that of the Kama, but at the same time many of the important species of both the latter are missing. The following is a typical list :—

Terebra noetlingi Vred.
Terebra samaranga Mart.
Terebra myuros var. *obeliscus* Vred.
Terebra protomyuros Noet.
Conus ineditus Mich.
Conus protofurvus Noet.
Conus odengensis var. *avaensis* Noet.
Oliva australis var. *indica* Vred.
Olivella minbuensis Vred.
Cryptospira birmanica Vred.
Clavilithes seminudus Noet.
Vicarya verneuili d'Arch.
Pirula promensis Vred.
Turritella angulata Sow. (many ribbed 1- and 2-ribbed).
Parallelipipedum prototortuosum Noet.
Leda birmanica Noet.
Cardita viquesneli d'A. et H. sec. Noet.

The fossiliferous horizons of the Yenangyaung exposed Peguan belong to this stage; it is well represented further south by the faunas from the higher part of the Tagaing Clays and overlying beds near Minhla, Malun and Migyaungye. A rich fauna of this stage occurs in the highest part of the beds of Sitsayan Shale type, just east of Sinbaungwe. In the upper sandy group of the Peguan, and only 1300 ft. from the local top of the Peguan, there is a fossiliferous horizon of this age immediately south of Thayetmyo. The exposure is on the shore. This occurrence indicates that the Kama Stage must be very thin or even absent at Thayetmyo,

and points to a strong local unconformity at the base of the Irrawaddian.

The Kama Stage.—Where it is present the Kama Stage is always represented by beds in which sands generally predominate and in which shales of Sitsayan type are absent. The most northerly typical fauna of this stage which has been found occurs at Thabutkyaw, between Migyaungye and Sinbaungwe. It may be said with considerable probability that the stage is not present north of Minhla unless the very highest beds of the Peguan which yield the *Arca submultiformis* (*Arca rhombea*) Facies-fauna in the Minbu and Gwegyo folds are of this age. Southwards from Sinbaungwe, however, an increasing thickness of beds must be ascribed to the Kama Stage. An exception to the general rule of southerly thickening is the area around Thayetmyo, where the stage is thin. At Kama itself the type locality is 2500 feet below the top of the Peguan. The fauna of the stage is a very large one, due to the remarkably rich "*Pleurotoma*-Shales" of Dalabe, Tittabwe, Myaukmigon and many other localities in eastern Thayetmyo District. There can be no doubt, it may be noted in passing, that the faunas from Kama, and Dalabe, etc., are from the same horizon. Only three of the gastropods from Kama have not yet reappeared in the lists from the new localities. Among the typical fossils of the Kama Stage may be noted the numerous members of the Terebridae and Pleurotomidae—all forms with a short vertical range—which have been described by Vredenburg. Other characteristic fossils include :—

Conus yuleianus Noet.
Conus odengensis Martin.
Oliva australis var. *indica* Vred.
Cryptospira birmanica Vred.
Cassidaria echinophora var. *promensis* Vred.
Pirula promensis Vred.
Rimella javana Martin.
Rimella promensis Vred.
Parallelipipedum prototortuosum Noet.
Arca Theobaldi Noet.
Arca burnesi d'Arch et H.
Cardita viquesneli d'A. et H. sec. Noet.
Tellina hilli Noet.
Tellina pseudohilli Noet.
Crassatella sp. nov.
Cardium subrugosum Noet.

Despite the fact that very careful search was made for evidence of a separate and distinct "Pyalo Stage" overlying the Kama

Stage, it must be admitted that the differences noted in the faunas of the very highest Peguan scarcely warrant the separation of a distinct stage. Faunas were examined from Pyalo itself from a few dozen feet below the Irrawaddian, whilst at Thanat (east of Allanmyo) a rich fauna was found but a few feet below the junction. Both faunas are typical of the Kama Stage and the same is true of the faunas from Kamagale. The latter locality is opposite Kama and the fossils come from the highest Peguan, that is some 2300 feet above the type locality of the Kama fauna. The main difference between these faunas, which must be regarded as from the higher part of the Kama Stage, and the typical Kama faunas lies in the abundance, almost to the exclusion of the normal form, of the spinose variety of *Cardita viquesneli*. The Pyalo Stage, founded, as it was, on the presence of *Ostrea latimarginata* would seem to indicate the danger of using members of the genus *Ostrea* as zonal forms without examining the evidence with the greatest of care.[16]

The Mapping of Lithological and Palæontological Horizons.

In this paper much has been made of the way in which the Palæontological stages cross the lithological horizons. The best way of illustrating this is to give an actual map of an area mapped in this way. Below is reproduced (by permission from the *Geological Magazine*, 1925) a sketch map of part of the riverine tract of Burma from Minhla to Thayetmyo. This sketch map was reduced, by permission of the Indo-Burma Petroleum Co., Ltd., from six-inch and one-inch surveys made by the writer in 1922–23. The map will show more clearly if the stages are each lightly coloured. Below is a diagrammatic section, reproduced from the same source, over the same area. In modern geological terminology, all the lithological groups are "diachronous."

Summary.

The oilfields of Burma occur as a long line from north to south near the centre of the synclinal trough of Tertiary rocks which forms the central region of the country. The main fields are also puckers in the main trough. The region of Tertiary rocks is an old sea-gulf, bounded on the east by the Shan Plateau massif and on

[16] The writer is indebted to the Geological Department of the Burmah Oil Co., Ltd. for information as to the exact locality from which the specimens of *Ostrea latimarginata* were obtained. The bed is situated in the stream immediately north-west of Sitsaba Village. Both above and below are other fossil-beds which, from specimens seen by the writer, appear to yield typical Kama faunas. The "Pyalo Stage" must therefore be dropped.

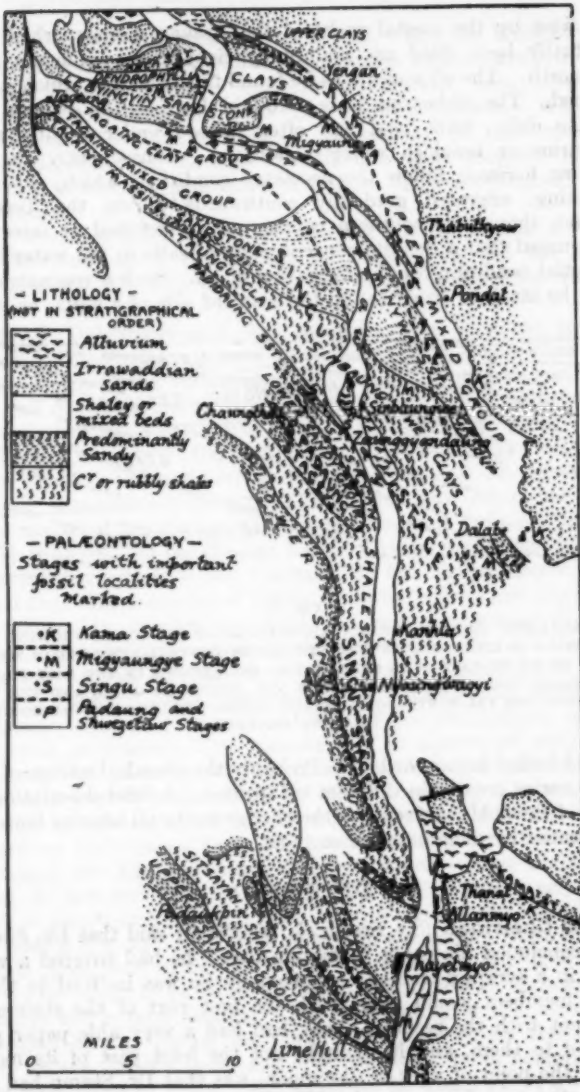


FIG. 7.

SKETCH-MAP OF PART OF THE RIVERINE TRACT OF BURMA, SHOWING THE RELATIONSHIP BETWEEN LITHOLOGICAL HORIZONS AND PALÆONTOLOGICAL STAGES.

the west by the crestal rocks of the Arakan Yomas, which has gradually been filled up, mainly by river-borne sediments from the north. The oil appears to be found in the beds in which it was formed. The oil-bearing beds were laid down on the seaward side of the delta, while coal was often formed under slightly more estuarine or brackish water conditions. Consequently the oil-bearing horizons follow the necessary conditions which, generally speaking, migrated gradually southwards during the Tertiary Period, though its southern course was interrupted at intervals. It is urged that a definite concentration of salts in the water is an essential condition for the formation of oil. Such a concentration may be attained either (*a*) on the seaward side of a delta, or (*b*) in

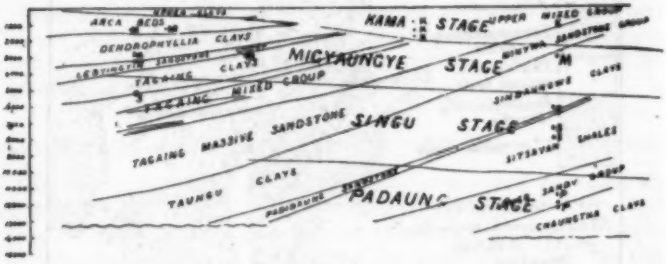


FIG. 8.

DIAGRAMMATIC SECTION, DRAWN APPROXIMATELY TO SCALE, SHOWING THE VARIATION IN LITHOLOGY IN THE PEGUAN OF CENTRAL BURMA FROM NORTH-WEST TO SOUTH-EAST OVER PART OF THE AREA SHOWN IN THE LAST FIGURE. IMPORTANT FOSSILIFEROUS LOCALITIES ARE SHOWN BY DOTS, AND THE WAY IN WHICH THE PALÆONTOLOGICAL STAGES CROSS THE LITHOLOGICAL HORIZONS IS VERY MARKED.

a land-locked lagoon or lake. Probably the chemical nature of the salts varies greatly in different oil regions. A brief description of each of the fields is given and the change in the oil-bearing horizons illustrated by diagrammatic sections.

DISCUSSION.

The Chairman (Sir Frederick W. Black) said that Dr. Stamp had concluded his paper by saying that "he had covered a wide field in a scrappy fashion." Personally he was inclined to think that members would agree with the first part of the statement but not with the second. They had had a very able paper presented to them, and he thought not the least part of its merit, from the point of view of discussion, was that Dr. Stamp had not hesitated to refer to the friendly differences of opinion between

rival geologists. In speaking of a field which he thought was called Yenanma in particular, Dr. Stamp had referred to Dr. Murray Stuart's views. The Institution had been favoured with a communication from Dr. Murray Stuart. Whether there would be time to read it *in extenso* at that meeting rather depended on the time that the discussion occupied, but at any rate it would be published in full in the Proceedings of the Institution.

He would ask Mr. Dewhurst to open the discussion, because Mr. Dewhurst knew the geology of Burma; he did not know where to put Mr. Dewhurst with Dr. Stamp and others, but he knew it well!

Mr. T. Dewhurst said that members were indebted to Dr. Stamp for presenting a general but sound account of the conditions of deposition of the Tertiaries of Burma. He would suggest that the gulf in which the sediments were deposited was perhaps not a simple gulf but a compound or twin gulf. The two parts of the gulf might be named after the present rivers as follows:—(1) The large western Chindwin-Irrawaddy sub-gulf, and (2) the small eastern Irrawaddy-Sittang sub-gulf. He was somewhat disappointed that Dr. Stamp had not thrown more light on the age of the "Axials" of the Arakan Yoma. About a year ago he (the speaker) had a look at the "Axials" in the Ngape district, and found that they consisted of highly contorted schists and phyllites, unconformably overlain by unaltered and moderately dipping shales. The striking contrast in the diastrophic effects of the two rock groups was so marked as to suggest a considerable time interval between their deposition. Dr. Stamp had made an ambitious attempt to show the whole of the stratigraphy of the Tertiaries of Burma. The speaker was in agreement with him generally, but also agreed that there was room for difference of opinion in regard to the details of the stratigraphy. It was only possible to refer to a few of the more important differences. In regard to the Eocene beds, he would point out that south of Paunggyi the Paunggyi conglomerates, which consist mainly of grits, do not rest directly on the "Axials" as there are some 2500 of intervening shales. Again, Fig. 4 showed the Yaw shales as forming a wedge, very thick indeed to the south. As a matter of fact that was incorrect, as the Yaw shales not only thin out to the north but also to the south, and therefore do not form a wedge but a large lenticle. The dove-tailing of the sediments described by Dr. Stamp was more clearly shown by the Pegus than by the Eocene beds, and was somewhat more complicated than was shown in Fig. 4. For example, he would insert a wedge of sandstone in the middle of the thick Sitsayan Shale—Padaung

clay wedge of Fig. 4. Apart from these points and a few others of minor importance, he was in agreement with the author regarding the general stratigraphy. Dr. Stamp was correct in stating that the time planes cross the condition stages, as it was obvious from only a cursory glance at the section dealing with the conditions of deposition that different kinds of sediment were being deposited at different places at one and the same time. In regard to palæontology, there had been far too much dependence on faunas from Pegu inliers where only very partial and small sections of the Tertiaries were exposed. It would have been far better to have constructed a range table from collections taken along the western outcrops where the whole of the succession was exposed for almost the whole length of the country. Although Dr. Stamp had been largely dependent on inlier faunas, he had made the best use of them in the palæontological and stratigraphical sections of the paper. In regard to the origin of oil Dr. Stamp had taken up a moderate and judicial attitude, and had tried to oblige all who believed that oil had been formed by the decomposition of organic matter of any kind. In his summary Dr. Stamp urged perhaps a little too strongly the importance of a definite concentration of salts in the water. Personally he inclined to the second alternative of the paper, namely, that a certain amount of concentration of salts might have been necessary for the growth of the bacteria requisite for the formation of the oil. However, there was perhaps some danger of over-stressing the importance of salinity. To a certain extent salinity carried with it its own condemnation in that if the water became too saline the fauna was killed off, and this removed one source of supply of organic matter necessary for the formation of oil. The second point deserving consideration was that the conditions which were essential for the retention of oil were also favourable for the retention of brine in the rocks; that led to an association of oil and brine which was not necessarily an association of cause and effect but perhaps merely of two co-effects arising from a common cause. He would suggest that the conditions suitable for oil formation were also suitable for the concentration of salts in the water. His own view was that oil was formed under conditions of reduction in what might almost be described as huge septic tanks which were also favourable for high concentration of salts. He would like to correct one or two statements in the paper relating to the oilfields. One was in connection with the description of Yenangyaung as being "a fine gentle dome, *slightly* elongated." As a matter of fact it was very much elongated, the developed part of the field being just over half a mile wide and nearly four miles long. The statement that Minbu is not closed to the south is inaccurate as it is quite definitely

closed. Moreover, he would point out that the Tagaing field should not be confused with the Minbu field as the two are separate and distinct. He was pleased to see the reference in the paper to the scientific development of the oilfields of Burma. It was doubtful if there were any oilfields anywhere which were more soundly and scientifically developed than were the oilfields of Burma. That was, of course, in the best interests of all concerned. There had been a certain amount of unavoidable congestion, particularly in the Native Reserves of the Yenangyaung field, but even the dangers which usually attend congestion had been carefully avoided. Sir Thomas Holland, in 1908, was President of an Oil Fields Committee appointed by the Burma Government to enquire into the congestion of boring in the Native Reserves of the Yenangyaung field, and certain measures were recommended by that Committee and accepted and applied by the Government. Those measures have now been in operation for nearly twenty years, and it was possible to state that they had been successful in preventing the flooding of the oil-sands by water. In conclusion he would like to take the opportunity of paying a tribute to early geologists who worked in Burma, and particularly to Dr. Thomas Oldham, the first Director of the Geological Survey of India. In 1855 Dr. Oldham took a trip up the Irrawaddy, and Dr. Pascoe stated that when visiting Yenangyaung, Dr. Oldham recognised that there was some connection existing between the accumulation of oil and the anticlinal structure of the field. Dr. Pascoe also stated that Höfer gave Dr. Oldham the credit of having been first to recognise that connection. The next man who recognised and commented on that important association was Sterry Hunt, who did so in 1863 in connection with the Western Ontario Fields. Later, many other Geologists in the United States recognised the connection between anticlinal structure and oil accumulation, although the anti-clinal theory was not tested and definitely established until this was done by I. C. White in the year 1885. On the same trip Dr. T. Oldham recognised the possibility of the occurrence of oil in commercial quantities at Yenangyat, long before even the first native well was drilled. Mr. G. E. Grimes, in 1897, mapped the Singu dome and recognised its possibilities. Moreover, the question of the asymmetry of anticlines and its effect on the disposition of oil-pools was one of considerable practical importance, and although some work on that problem might have been done elsewhere he understood that it was first definitely settled in connection with the Yenangyat field. It was therefore a pleasure to have the opportunity presented by the present occasion of paying a tribute to those early workers who not only helped to elucidate the geology of Burma,

but even played no inconsiderable part in the discovery of some of the fundamental principles of petroleum geology.

Mr. E. H. Cunningham Craig congratulated Dr. Stamp on having given such a very well reasoned and well illustrated paper. If he might be allowed to say so, Dr. Stamp showed a remarkably good grasp of the geology of Burma. He especially liked the way in which Dr. Stamp had pointed out so clearly the practical importance of studying the deposition of two series in the most scientific way, especially with regard to lateral variation and the fluctuations in the movement of the delta. Of course, some of Dr. Stamp's points were not by any means new to those who had worked in Burma. The general formation ot the gulf, the advance of the delta from the north and its various fluctuations, and the fact that the oil horizons rose in the series and across the time planes when traced southward were all points which were familiar a good many years ago, and in fact most of them had been published some 14 or 15 years ago.

There was a small correction he would like to make with regard to the Peguan Gulf.

The Arakan Yoma ridge had not existed very far south to begin with. Later on, as the movement went on, it had extended gradually further and further.

There was another point about which Dr. Stamp might have said something, and that was about the existence of a line, either a chain of islands or a ridge, of metamorphic rocks, which came out somewhere towards the centre of the gulf. Volcanic phenomena took place along it in Irrawaddy times. It was seen to the north of Pakokku and also at Popa, and it extended no doubt into the Pegu Yoma. Along this line there was in some places a very great fault which brought down the Pegus on the one side, and along that fault the volcanoes started. The metamorphic rocks were found there unconformably overlaid by strata of Irrawaddy age. Therefore it seemed probable that if those were islands in Irrawaddy times, they had been probably dry land, in Peguan times. To the east of that volcanic line most of the strata were found, although of Peguan type often, to be of Irrawaddy age; that was to say, that although the Irrawaddys were being formed in the western part of the gulf, there were marine rocks very like Upper Pegus forming to the eastward. Therefore the cross section which Dr. Stamp showed had to be modified slightly. The rocks to the east of Popa were much higher as a rule than the Peguans which Dr. Stamp showed in the various folds on the western side of the volcanic line.

There was one other point, and that was the variation in the strata from west to east. He quite agreed with Dr. Stamp that

most of the sediment came from the north, but there were very large littoral sands laid down close to the Yoma ridge, and there was a west to east variation also. The study of that variation was very important from the oil-producing point of view. In 1908 he had found it possible to draw a line through a good part of the Burma fields showing the eastern limit of probable producing oil sands, and that line had not been modified since. It had been extended further south and it had been extended north, but it had remained as a line of which one could be fairly sure. He could admit that at one time when a certain field had been discovered lying almost exactly on the line, there had been a good deal of doubt as to whether that field would ever give production or not, but after considering all the evidence again he came to the conclusion that although that field might yield gas and perhaps "shows" of oil, it was really too far eastward to be favourably placed with regard to the east and west variation, although it was well situated as regarded the north and south variation. The conclusion proved correct.

He desired to say in conclusion that Dr. Stamp's paper was the type of paper which was required about all countries where technologists were working. It combined stratigraphical, lithological and palæontological knowledge, well balanced and put in their proper places; in fact it was the kind of paper which the Institution should welcome most heartily.

Dr. Murray Stuart, who was unable to be present owing to illness, sent the following written contribution to the discussion, which was read in abstract by Mr. T. Dewhurst:—

In describing the accumulation of the Burma Tertiaries, Dr. Stamp pictures a narrow gulf bounded on the east and north by a massif of Pre-Tertiary rocks and on the west by what we may call the Arakan Yoma Range. Into this gulf, Dr. Stamp pictures one or more great rivers pouring sediment from the north and so slowly filling up the gulf in a north to south direction. This would result in a lateral variation in the accumulated sediments in a north to south direction. Dr. Stamp is somewhat vague about it but I take it that he disagrees with my interpretation of the known facts, namely, that the Arakan Yomas formed a long narrow island in Pegu times and that the gulf pictured by him did not exist. If this is so, then it is difficult to understand what river he supposes could have brought sediment into Burma from the north. I am fairly intimately acquainted with the extreme north of Burma and I think that I am the only geologist who has more than touched on the fringe of this area. I have actually walked along the courses of most of the rivers and I have no hesitation in saying that not only do no rivers enter Burma from the north but that

there is no evidence that any did so in Tertiary times, other than the Tibetan Brahmaputra which discharged its sediments against the northern end of the Arakan Yoma Island.

As most Atlases are incorrect in their representation of the topography of this corner of the world it may not be out of place to review briefly what the facts are. The Irrawaddy, which has its source in Tibet close to the source of the Brahmaputra, flows eastwards through Tibet into China and then turns southwards through China parallel to the Salween and the Mekong. After flowing southwards for some distance, the Irrawaddy makes a sensational bend to the west (known as the Tarôn bend) and enters Burma from the east. There it joins up with the Nam Tamai to form the N'mai Hka, which flows southwards and eventually joins up with the Mali Hka above Myitkyina to form the Irrawaddy. Dr. Stamp points out that the Pre-Tertiary massif forms a plateau with an average elevation, in the Shan States, of over 3000 ft. The Putao plain, which is situated on the massif some three hundred miles north of the country shown on Dr. Stamp's Fig. 1, and along one side of which the Mali Hka flows, has an elevation of about 1100 ft.—in other words it is about the same height above sea level as Yenanma. It will be seen on Dr. Stamp's Fig. 1 and Fig. 3 that the Irrawaddy leaves the old massif of Pre-Tertiary rocks near the present site of Mandalay. Now in its course through Burma over the massif of older rocks the Irrawaddy shows no sign of having deviated from its original course. The same thing applies to the tributaries of the Irrawaddy in Northern Burma. These tributaries are bounded on the north by a watershed formed by a range of mountains, which is continuous with the Patkai Range (the present northern continuation of the Arakan Yomas). This range of mountains—sometimes called the Nam Kiu Range—is not part of the Himalayas, but is the watershed between the Irrawaddy and the Brahmaputra drainage. It is part of the old Pre-Tertiary land and is composed mainly of granite. It is difficult to see, therefore, what rivers Dr. Stamp imagines poured enormous quantities of sediment into his Burmese gulf from the north in Pegu and Irrawaddy times, and where they collected the sediment from. As his Fig. 1 shows, the Irrawaddy and its tributaries poured sediment into the supposed gulf, not from the north, but half way down the eastern flank of the gulf, and if the Arakan Yomas were not an island in Pegu times then the Brahmaputra could not get into Burma, and one is left with the melancholy picture of a gulf with no river of any size whatsoever coming into it from the north.

Dr. Stamp is inclined to discount the Arakan Yoma Range as a source of the sediment that was deposited over Burma during

Pegu and Irrawaddy times, but it must be remembered that the present centre of the range consists in places of schists of unknown age and that elsewhere sediments of Triassic, Jurassic, and Cretaceous age are known to occur, while the foothills are of Eocene rocks. It is obvious, therefore, that since Eocene times a vast thickness of Eocene and older rocks has been removed from the range by denudation and erosion. It seems reasonable to assume, moreover, that about fifty per cent. of the amount removed by denudation and erosion during Pegu and Irrawaddy times was contributed towards the formation of the Pegu and Irrawaddy strata of Burma. It must be remembered that elevation of the Arakan Yomas was taking place throughout Pegu and Irrawaddy times, and it would seem in consequence that it must have taken a mighty river coming in from the north, carrying an enormous amount of sediment, to so overwhelm the sediment being supplied laterally from the Arakan Yoma mountains as to establish the north to south lateral variation postulated by Dr. Stamp. Dr. Stamp states definitely that there is evidence that little, if any, of the Tertiary sediments were derived from the Arakan Yomas. I should like to ask what this evidence is, and what extraordinary phenomenon of nature he assumes to have arrested the action of denudation and erosion on the Arakan Yoma mountain range during Pegu and Irrawaddy times? There is another small point just worthy of consideration. The Irrawaddy entered the gulf laterally about half-way down the eastern flank of it. Dr. Stamp would appear to agree with me in this, unless his illustrations are wrong. Now the Irrawaddy rises close to the source of the Brahmaputra and has come a longer distance by the time it reaches Mandalay than the Brahmaputra has when it reaches Sadiya, so that even if the Tibetan Brahmaputra poured all its sediments into Burma, which it most certainly did not, it seems reasonable to suppose that the Irrawaddy must have been pouring a still greater quantity of sediment into the middle of the gulf from the eastern side of it. If we assume that denudation and erosion were operating on the Arakan Yomas during Pegu and Irrawaddy times, then the material derived from them has to be added to the material supplied from the opposite shore in calculating the amount of material supplied laterally into the gulf; and to completely dominate this and establish the north to south lateral variation supposed by Dr. Stamp one has to add to the Brahmaputra something catastrophic, such as a continual cloud burst extending over Pegu and Irrawaddy times. Fortunately the phenomena observed by Dr. Stamp can be explained more simply.

Before taking this up, however, there is one point in connection

with Dr. Stamp's hypothesis I should like to draw attention to, and that is this:—If for all practical purposes the material now forming the Pegu strata and Irrawaddy strata may be considered to have been discharged into a gulf from the north, as pictured by Dr. Stamp in his Fig. 2, then at any particular time the rocks suitable for the accumulation of oil must have extended as a belt stretching approximately east and west, *right across the gulf*. At the end of Pegu times the oil-bearing rocks must have extended as a sheet stretching from one flank of the gulf to the other in an east and west direction, and from north to south of the gulf. It would not be horizontal in Time, however, in that each successive southerly "belt" would be slightly younger than the one to the north of it. This is another way of saying what Dr. Stamp says when he emphasizes the fact that the palæontological stages cross the lithological horizons in Burma, and gives Fig. 7 to illustrate the point.

Now I am open to correction, but I am distinctly of the opinion that the formation of mineral oil is the result of certain conditions, and that given those conditions the exact time when they occur has no effect, practically speaking, on the resulting formation of oil. I am considering Time as a sort of fourth dimension, and saying that given all the correct conditions for the formation and accumulation of oil, such conditions may be moved in Time without affecting the question of oil formation. If I understand Dr. Stamp correctly he is of the opinion that conditions suitable for the accumulation of oil-bearing strata moved forwards in Time and southwards in Direction during the deposition of the Pegu strata in his presumed Burmese gulf. It would seem to follow therefore that the matter of vital interest to the oil geologist in Burma is the question of the lithological horizons, since these result from definite combinations of conditions, and that the question of whether these lithological horizons coincide with the palæontological stages, or whether they cross them, has no practical bearing on their oil-bearing, or barren, nature. The palæontological stages are of great academic interest in Pure Science, of course, but I am considering the matter at present from the point of view of the geologist in search of oil. In 1910 I attempted to do something, the same sort of thing that Dr. Stamp has done in this paper, when I named the uppermost marine beds in Lower Burma the "Marine Irrawaddies." My doing so raised such a storm in the Geological Survey of India that I quickly appreciated the confusion that would result from trying to correlate in Time by the use of names hitherto used to designate lithological formations, and at the request of my colleagues I altered the name of the formation to Akauktaung series, and included it in

the Pegu system. It is, I suppose, the irony of fate that those who objected to my "Marine Irrawaddies" found themselves forced to recognize "Fresh-water Pegus" in the north. For the past fourteen years I have always worked and thought in lithological horizons in Burma, and have not attempted to correlate in Time.

In 1873 Theobald classified the lithological formations of the Pegu system of Lower Burma into the following sequence:—

4. An upper sandstone formation (Mogoung sands).
3. The Kama clay formation.
2. The Prome sandstone formation.
1. The Sitsayan shales.

Because of some remarks that Dr. Stamp makes I should like to testify to the excellence of Theobald's work. The conditions under which he worked were particularly trying, and it is no exaggeration to say that the geological mapping done by him in Burma has never been surpassed, and I doubt if it has been equalled, by any other geologist since his time. I am in a position to speak, because I have been over a very large proportion of the territory mapped by him. To return to his lithological horizons, the Sitsayan shales are a deep water marine formation, not suitable for the formation or accumulation of oil. The Prome sandstone formation consists of massive calcareous sandstones, also not suitable for the formation or accumulation of oil. The Kama clay formation consists of alternating beds of soft sands and clays or shales, and is known to be petroliferous. The upper sandstone formation, which corresponds to my Akauktaung series, is easily distinguishable from the underlying Kama clay formation by the yellow colour of the sands and the less blue colour of the interbedded clays. In 1910 and 1912 I pointed out that there is an unconformity at the base of the Akauktaung series. In 1922 Dr. Stamp cast doubt upon the existence of this unconformity. I can assure him that there is no doubt about it whatsoever in Lower Burma. Recently I have been in charge of a party of geologists, engaged in geological mapping on the scale of sixteen inches to the mile, and it has become evident that overlap is common between the other members of the Pegu formations, so that it is possible that the unconformity mapped by me at the base of the Akauktaungs may be more of the nature of overlap than of ordinary unconformity. Dr. Stamp now comes forward and says that the Kama clay formation of Theobald is virtually a myth, and that it consists of only the bottom clay band—one amongst hundreds—of Theobald's formation. It would be equally incorrect for me to say that Dr. Stamp is virtually a myth and that he

consists only of the soles of his boots. What are we to suppose Theobald imagined existed between the basal clay bed of his Kama clay formation and the basal bed of his Mogoung sands—void?

As a matter of fact the Kama clay formation is the most important lithological horizon recognized by Theobald, in that it is suitable for the accumulation and retention of oil. The petroliferous formations of Yenangyat, Singu, Yenangyaung, and Minbu all belong to the lithological horizon of Theobald's Kama clay formation. I have no doubt that Dr. Stamp would like to contest this statement of mine, which is one that I made in 1910, but I would ask him to look at his Fig. 4.

If we consider his upper sandy group, which obviously includes both Theobald's Kama clays and my Akauktaung series, we find that as a lithological horizon it comprises the Pegu strata of the Yenangyat, Singu, Yenangyaung, and Minbu fields and followed southwards becomes his Migyaungye and Kama palæontological stages. This far I agree with his diagram. I do not agree with the oil horizon of the Padaukpin dome being attributed to a lower formation. In the centre of the dome there are patches of Irrawaddy gravel left from the denudation of the Irrawaddy conglomerates and from this and other reasons it is obvious that the strata exposed belong to his upper sandy group.

Just as the Kama clay lithological horizon crosses lower palæontological stages when traced northwards, so does the underlying massive Prome Sandstone formation; and when traced northwards to the latitude of the Minbu field it becomes the Shwezetaw sandstone, while the overlying Padaung clays belong to the Kama clay lithological horizon.

These, however, are minor details.

The diagram gives another very interesting piece of evidence. If we look at the base of the Irrawaddian we find either a conglomerate or the red bed, occurring over the underlying Pegus, but from Singu northwards this conglomerate no longer occurs at the base of the fresh-water beds, but continues on in the same plane as it did on the left of the diagram. As shown on the diagram it would appear to represent a definite stratigraphical horizon, and that gives rise to the thought that speaking generally the lithological horizons may represent definite geological horizons and that the palæontological stages need not necessarily be Time horizons. If we think of Dr. Stamp's picture of a gulf it is obvious that it was only open to the ocean at the south, and therefore any introduction of new species into the marine fauna of the gulf would take place from the south. According to my view of the case, that the Arakan Yomas formed an island against the northern

end of which the Tibetan Brahmaputra discharged its sediments the same reasoning would apply. The fresh water of the Brahmaputra would prevent marine forms entering the arm of the sea between the Arakan Yoma Island and the Chinese mainland from the north, and the only means of entrance would be from the south. Now Dr. Stamp's Siphonostomata when alive were not exactly rapid, considered from the point of view of movement, and it seems reasonable to assume that it would take some considerable time for a new species to spread up to the northern end of the gulf after it first appeared at the southern entrance to it. It seems almost conceivable that Dr. Stamp's Singu fauna might have been thriving at Singu contemporaneously with his Kama fauna thriving in the south. This might quite easily give the phenomenon of palæontological stages crossing the lithological horizons, but in this case the lithological horizons would correspond approximately with Time horizons while the palæontological stages would cross the Time horizons. This would be more in accordance with my interpretation of the geographical conditions that existed in Pegu times than it would with Dr. Stamp's picture of a gulf and all the sediment coming in from the north. The study of the remains of free swimming forms certainly supports my conception of the case. This Institution is not one that should be inflicted with palæontological controversy, however, and I do not propose to go further into this aspect of the case.

I will, however, go further in the matter of correlation of lithological horizons, and suggest that the formation definitely recognized by both Grimes and Noetling in the oilfields under the name of the Yenangyaungian, which was characterized by the yellow colour of the sands and the less blue colour of the interbedded clays, is the same lithological horizon as my Akauktaung formation in the south.

I do not know what theory Dr. Stamp favours to explain the origin of oil, but certainly do not understand why the salts in the water on the seaward side of a delta should be concentrated. Referring to the possible connection between the fossil-wood of the Irrawaddy system and the oil in the Pegu system, Dr. Stamp rather gives the impression that the general form of occurrence of the fossil-wood is in long logs. I am aware that such are known, but although I have travelled extensively over Irrawaddy rocks during many years, and have seen hundreds of tons of fossil-wood, I have never seen one of these logs, nor any accumulation of fragments that would appear to have resulted from the disintegration of one. Dr. Stamp insists on the fossil-wood being silicified *in situ* after being entombed in sediment. That being so, I should like to ask him where the wood was derived from,

how it got into the sediments, how it was silicified, where the chemical elements composing the wood went to and how combined with one another, and finally how any vegetable oil from the wood could have migrated to marine sediments in the south?

With regards to Dr. Stamp's statement that the coals of Burma never contain marine fossils I have on the table a specimen of lignite from near Mawlaik containing fossil fish teeth.

With regards to the question of whether the Arakan Yomas were an island or not, and whether for all practical purposes the sediments forming the Pegu system of Burma were derived from the north or chiefly laterally, if Dr. Stamp is correct then there is no reason why paying oilfields should not be found in, say, Western Thayetmyo, provided that suitable anticlines of Pegu rocks composed of the right lithological formations are located. If, on the other hand, I am correct, then even if the structures and the rocks are right, the situation is too close to the Arakan Yoma Range for the rocks to be likely to contain large quantities of oil. The results of fairly extensive drilling in this area in the past would appear to support my contention. Dr. Stamp mentions the fact that the overthrust that I have described as existing near Yenanma is disputed by many geologists who know Burma thoroughly well. He also quotes me as saying that the oil at Yenanma comes from a hidden anticline. I thought I had made myself clear, but apparently what I have said has given Dr. Stamp quite as erroneous an idea as he has formed about Theobald's Kama clay formation. I do *not* think that the oil comes from a hidden anticline. Regarding the overthrust it is perhaps worth mentioning that the fault was not mapped originally by me, but by some of my colleagues on the Geological Survey of India. It was the geological information given by numerous wells that induced me to set a party of geologists mapping for two years along and near the fault line on the scale of sixteen inches to the mile. The result of that mapping plus my own work, combined with the information given by a large number of wells, convinced me that the fault is an overthrust. I doubt whether any other geologist knows quite as much about that particular neighbourhood as I do. Even without my evidence, if one glances at the maps of the Geological Survey of India the fact that it must be an overthrust hits one in the face.

In conclusion I should like to congratulate Dr. Stamp on the large amount of valuable work he has done, and particularly on having reconciled the two outstanding and apparently irreconcilable statements in Burmese geology, viz.:—mine, made in 1910, that the lithological horizon of the oil-bearing strata of the main oilfields is the Kama clay horizon, and Vredenburg's, made in 1921, that the fauna of the oil-bearing strata of the main oilfields

is the same as that characterizing the Sitsayan Shale lithological horizon in the south. Thanks to Dr. Stamp the explanation is now clear, and the two statements are obviously in perfect harmony, the explanation being that the palæontological stages cross the lithological horizons. Having experienced the confusion that arises from the same name being given to lithological horizons and to palæontological stages, I would suggest to Dr. Stamp that he would be doing a service to the geology of Burma if he would designate the palæontological stages in some distinctive way—say by the letters of the Greek alphabet—in order to help straighten out the confusion that has existed since 1921, and so make quite clear whether one is talking of a lithological horizon, or of a palæontological stage that may possibly cross that lithological horizon as well as others.

Dr. Stamp, in reply, said he would attempt to deal in order with some of the major points that had been raised. Unfortunately in a short paper of the sort under discussion there were always numerous subjects with which one would like to deal, but with which one was precluded from dealing owing to the question of space; and he was afraid under that heading came both Mr. Dewhurst's remark about the nature of the gulf—the existence of a twin gulf—and Mr. Cunningham Craig's point with regard to the so-called chain of islands. It was perfectly true that there was a very great difference between the character of the western half of the gulf and the eastern half. As a matter of fact in the last three years since he had left the Indo-Burma Petroleum Company he had been working with his assistant, Mr. Chhibber, on the volcanic rocks which Mr. Cunningham Craig had dealt with, and which lay along the line between the eastern and western halves of the gulf. He had spent last Christmas and New Year at Mt. Popa trying to locate the fault which Mr. Cunningham Craig had mentioned. There was a tremendous difference between the two halves, and he thought "twin gulf" best expressed it, provided, one remembered, that in talking about a twin gulf one did not mean that there was a definite land barrier down the centre. Possibly a submerged shoal, with here and there islands, would meet the case.

He must correct what he was afraid had been a slight misapprehension with regard to Fig. 4. In drawing such a diagram as Fig. 4 one must have some line to take as, should he say, a datum line, and in drawing that diagram he had taken his horizontal lines to be the Time planes; that was to say, the Yaw stage, the Shwezetaw stage, the Singu stage, and so on, were separated by horizontal lines, and hence the wedges of strata shown were not to scale. If one considered the diagram as to scale then the Sitsayan

shales shown to the south were much too thick in relation to the sandy beds to the north. As far as Time deposition was concerned, possibly 100 ft. of Sitsayan shales were equivalent to 1000 ft. of the more sandy beds. So he could not possibly on such a diagram show the Yaw shales as a lenticle. Perhaps he should have had a second diagram drawn to scale as far as the thickness of the beds was concerned, and then he would have been able to show such things as the lenticular nature of the shales. It was simply that he had had to take something as a straight line, and he had chosen the Time planes and had fitted in the lithological groups to fit them.

He must confess that he thought one of the great troubles which existed still was the use of the name "Sitsayan shales." Possibly he was not using the term "Sitsayan shales" in the same sense in which it was used by the B.O.C. It is a use which had perhaps developed, as he had worked himself in the region. There certainly were sandy groups right in the heart of his Sitsayan shales, so that whether Mr. Dewhurst called the shales above these the Sitsayan, or the ones below, was a point of some importance. Dr. Murray Stuart was undoubtedly still using the Kama clays as equivalent to what he himself had labelled the Sitsayan shales. He knew that in the Thayetmyo district the great thickness of clays which to himself formed the upper part of the Sitsayan shales, Dr. Murray Stuart regarded as Kama clays. Hence there was a great difference of opinion there. He was glad to know that Mr. Dewhurst backed him up in his consideration as to the relative unimportance of the Kama clays.

It was true that he had used the inlier faunas when considering palæontology. The reason for that was that an enormous amount of work had been done on the faunas of those inliers by Mr. Vredenburg. When one knew that geologists had carried out such work it seemed almost the only possible thing to do was to carry on and try to use their results as far as possible. It would have been a presumption to have started *de novo* and to have made new palæontological stages. He had followed the method of taking what had been done before and of trying to use the results as far as possible. He had objected to one of Mr. Vredenburg's stages and had suggested the addition of one between his Kama and Singu Stages, namely, the Migyaungye Stage.

Perhaps there had been a little confusion with regard to his remarks on salinity. He had said nothing of the connection between oil and brine. His remarks on salinity had been based on the character of the fossils which occurred in the oil-bearing beds; and the character of the fossils was such that it indicated that those animals were living in brackish water conditions or in

sea water which was rather less rich in salts than the water of the open ocean.

With regard to the remark that if the water became too saline the organic matter would automatically disappear, did not that pre-suppose that the organic matter originated and lived where the oil had been deposited? He had said nothing about that, and did not consider that that was a justifiable conclusion. After all, the vegetable material, or whatever it was, might have been brought by those rivers from a distance.

With regard to the corrections which Mr. Dewhurst had suggested, perhaps he should not have spoken about Yenangyaung as a slightly elongated dome, when it was seven or eight times as long as it was broad. Perhaps the term "dome" could be left entirely by itself.

With regard to the three northern fields of Minbu and his remarks that the field was not closed, he had been thinking of it in relation to the other great fields. Yenangyat and Yenangyaung were enclosed by Irrawaddian rocks.

The Tagaing Structure was absolutely distinct from the Minbu Fold with its crest maxima, but he was under the impression that there was not actually a tongue of Irrawaddian between them, but only a strip of the highest, sandy Peguan.*

With regard to Mr. Cunningham Craig's remarks on the Arakan Yoma Peninsula, it was quite true that it grew southwards as well as in breadth as the Tertiary period had gone on, and one could not say how much of that ridge was actually above sea level and how much actually formed the submerged shoal. One knew that it did act as a barrier between the two basins of deposition.

The question of the Peguan chain of islands and a volcanic line was a most fascinating subject. The exact nature of the boundary between the two halves of the gulf was particularly difficult to determine. It was true that one could see the great difference in the nature of strata on either side. Perhaps the so-called Peguan on one side was the Time equivalent to the Irrawaddian on the other.

The lateral variation of sediment was perhaps even more difficult to study than the variation from north to south. One would expect, after all, littoral conditions to follow along the line of the Arakan Yoma Peninsula, and he thought it was correct to say that if that was so there must therefore be variation from east to west. It was interesting to relate that Mr. E. S. Pinfold, when he had discussed with him the very diagram which was before the meeting,

* Mr. Dewhurst has since assured the writer that there is actually a tongue of Irrawaddian rocks separating the two.

had said "Yes, but you must have the complementary diagram from east to west." His reply had been "Can you suggest where I can find the data on which to construct it?" He was afraid he was still in that position. He had got together sufficient data to construct the north and south, but he had not sufficient to construct a diagram showing the variation from east to west. It was true that, in order to make the paper complete, there should be that corresponding east-west diagram.

With regard to Dr. Murray Stuart's attack, Dr. Stamp said it might be best to consider the points raised in order. In the first place we are treated to a gratuitous lesson in fictitious geography. Somewhere about half a century ago, it was indeed thought that the Irrawaddy had its source somewhere near that of the Brahmaputra, and this belief was embodied in a number of old maps which Dr. Murray Stuart appeared to accept as telling the truth. Actually a slight error of a thousand miles or so had been made, the Irrawaddy did not wander about Tibet and China making "sensational" bends, but both the head streams—the Mali Hka and the N'mai Hka—rose quietly within the confines of Burma itself. On these points reference might be made to the maps and accounts of Kingdom Ward (*e.g.*, *Geog. Jour.*, Vol. LXII., 1923, p. 6 and map, p. 9).

Even supposing Dr. Murray Stuart's account had been correct, it was difficult to reconcile his statement that "no rivers enter Burma from the north . . . there is no evidence that any did so in Tertiary times . . ." with his account of the supposed wanderings of the Irrawaddy in Tibet. If Tibet and the adjoining parts of China did not lie to the north of Burma it would be interesting to know what countries did.

Dr. Murray Stuart's own maps supplied the evidence for the derivation of much of the sediment from the north. A glance at his map (*Records Geol. Surv. India*, Vol. LIV., pl. 29, 1923), showed huge areas of Tertiary sands stretching in Burma as far north as Putao on the east, and right across into Assam on the west. Dr. Stuart now seemed to imagine, in some extraordinary way, that the Irrawaddy had occupied exactly its present course since early Tertiary times—probably some 10,000,000 years. He seemed unacquainted with the widely accepted view that, not very far back in its history, the present Chindwin formed the main stream of the Upper Irrawaddy (see Gregory, *Geog. Jour.*, Vol. LXI., 1923, p. 153). Whether the early Arakan Yoma ridge should be described as a peninsula or as an island did not seem to be a very important point. It separated the Assam and Burma basins of deposition, though in the extreme north tracts of fresh-water sands may connect the two. Dr. Stuart, who was so anxious

that it should be regarded as an island, now carefully pointed out that the Patkai Range—just where he would join the two basins of deposition—consisted of a ridge of granite.

It was unnecessary to repeat that the existence of littoral conditions along the Arakan Yoma had been recognized, and it would be foolish to deny the derivation of some sediment from this area. Therefore conditions suitable for the accumulation of oil would not have stretched right across the gulf from east to west—indeed it had been shown in the paper how they were restricted very largely to the central line of the main gulf.

No one who had worked seriously in Lower Burma could fail to appreciate the magnificent work of W. Theobald. It was all the more serious, therefore, when later geologists took it upon themselves to alter his words to suit their own ideas. Theobald *did not* separate a "Kama Clay formation." His words should be allowed to speak for themselves :—

(1) "Pegu Group—An enormous succession of sandstones and shales of unknown thickness and not usually fossiliferous. *Particular beds*, however, contain fossils in profusion, *e.g.*, Blue Kama clay, highly fossiliferous" (*Records Geol. Surv. India*, Vol. II., 1869, p. 80. This is the first mention of the Kama Clay).

(2) "Some very fossiliferous blue shales which I have termed Kama Clay . . ." (*Mem. Geol. Surv. India*, Vol. X., 1873, p. 85. There is no suggestion anywhere of a Kama Clay formation).

It was indeed regrettable that Dr. Stuart, after having graciously admitted his mistake in the recognition of the Kama clay (see *Records Geol. Surv. India*, Vol. LI., 1921, p. 237), should again disinter the past.

Dr. Stuart's suggestion that the Singu fauna might have been living happily at Singu when the Kama fauna was in existence at Kama was of interest in view of his (Dr. Stamp's) attack on the modern school of palæontologists (see "Some Practical Aspects of Correlation : A Criticism," *Proc. Geol. Assoc.*, Vol. XXXVI., 1925, p. 11). As one who had championed the very objection now put forward by Dr. Stuart, it must be urged that the contemporaneity of each great palæontological stage in Burma was satisfactorily proved, and it must be borne in mind that the 2½ million years during which the Peguan was accumulating had only been divided into five or six divisions. The stage faunas had been allowed half a million years to travel a hundred and fifty miles.

The fossil-wood of the Irrawaddian rarely (except in definite conglomeratic beds) occurred as rolled fragments. The fragments were angular and cannot have been transported far. Sub-aerial denudation had scattered the fragments widely over the surface. But *in situ*, in the sands themselves, long logs split many times

across, were the usual mode of occurrence. Most rivers were capable of floating logs of wood, which eventually became water-logged and sank, or stranded upon sandbanks became silicified. The silicification of wood under sub-aerial, desertic conditions, was described in most geological text-books, reference to original authorities might be made in the publications of the Geological Survey of Egypt.

The coals of Burma certainly contained fish teeth. But so did fresh waters (as well as salt) contain fish.

Dr. Stuart showed very clearly in his published section the Yenanma Oilfield over a hidden anticline. It was much to be regretted if the anticline were drawn accidentally and that it was intended to convey the impression that all the oil was held up in the fault plane (see *Journ. Inst. Petr. Tech.*, Vol. 11, 1925, p. 484). The section had, he believed, been reproduced also in Dr. Stuart's recently published book.

Regarding the suggestion that Greek letters or new names should be used to designate the palæontological stages, it seemed unwise further to burden Burmese geological literature when the main facts were clear.

Finally there was one point which he desired to emphasize very much. He had not in the paper made very much reference to the enormous amount of previous work which had been done in Burma. At the same time he did not want anybody to think that the bulk, or even a considerable portion, of the paper as it stood was his own work. It was certainly not. He had attempted to bring together the various published ideas, together with certain other matters which had come into his hands, and he had possibly added little touches here and there as a result of his own work. No one was more anxious to disclaim than he was the credit for a considerable portion of the paper as it stood. It depended entirely on the large amount of work which had been done by geologists for the last 80 years in Burma.

A hearty vote of thanks to Dr. Stamp concluded the meeting.

The Final Closing-in of Potrero 4.

By A. E. Chambers, A.M.Inst.C.E., and R. H. Ames (Members).

In 1923 one of the authors had the honour of submitting to the Institution a paper* detailing the history of Potrero No. 4, up to the year 1919. It is now considered that a further communication should be presented in order to make the record complete and also because the numerous practical difficulties since met with and overcome in finally closing this well may be of interest.

To make clear the final events in the life of this well, it is advisable to state shortly the condition in which it was left in 1919.

Fig. 1 shows the well as it was shut-in at that date; the top of the casing was closed by a bell nipple and valves, installed in 1911. The condition of this nipple and its fittings was unknown, but they

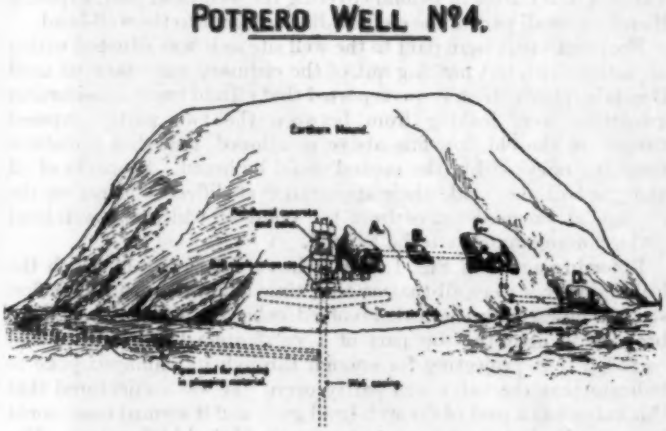


FIG. 1.

were thought to be badly damaged by the fire through which they had passed in 1914. The nipple and the valves surmounting it were encased by reinforced concrete and by coke deposited on it at the time of the fire. A slab of what was supposed to be concrete,

* "Potrero No. 4. A History of One of Mexico's Earliest and Largest Wells." Journ. Inst. Petr. Techn., 1923, ix., 141—156.

some 18 in. thick by 20 ft. square, surrounded the well at about the level of the bell nipple; this slab was the foundation upon which the concrete house, subsequently removed, was erected in revolutionary times in 1913. The whole well and concrete slab were covered by a large earthen mound, used when putting out the fire in 1914, a small portion of which had, however, been removed in 1919. The well, it may be recalled, was from March, 1915, to December, 1918, producing from leaks at the well-head some 18,000 barrels of oil daily; this oil was collected and pumped to the adjacent tank farm. In December, 1918, the well started to give emulsion and was closed by pumping in Indian corn, broken brick, cement and chopped rope until no trace of leakage was observed coming from around the bell nipple and valves on the well-head. The pumping of this material was effected through a 4-in. pipe, which had been fitted with a milling cutter and inserted in the casing some 13 ft. below the bell nipple, as described in the paper previously referred to. This plugging appeared so effectual that nothing more was done to the well than to disconnect and plug a short length of flow-line and dig a trench into the earth mound covering the well-head gear, exposing thereby a small part of the old flow-line adjacent to the well-head.

Frequent visits were paid to the well site as it was situated within an active field, but nothing out of the ordinary was observed until December, 1925, when it was reported that oil and gas in considerable quantities were leaking from between the two partly exposed flanges on the old flow-line above mentioned, and that a distinct rumbling noise within the mound could be heard. Seepages of oil and gas had also made their appearance at different places on the mound, at short distances from the point at which the well-head fittings were supposed to be located.

Referring again to Fig. 1, "A" shows the cavity in which the leaking flanges were all that at that time could be seen. The first step to investigate the leak involved enlarging this cavity, which brought to light the top part of a valve stem badly burned and corroded, but projecting far enough through its damaged yoke to indicate that the valve was partly open. It was conjectured that this valve was a part of the well-head gear, and it seemed there could be no doubt that these flanges were a part of the old flow-line. Pits were immediately dug to ascertain its direction and limits. "B," "C," and "D" indicate the discoveries made, and at these places pipeline saddles were put on, in order to determine the pressure existing within the line, and what volume of flow might be expected, as it was hoped that the leakages were simply the result of accumulated pressure in the upper casing and flow-line, due to the somewhat porous nature of the plugging material used in 1919, and that, with a larger orifice for escape than that afforded by the

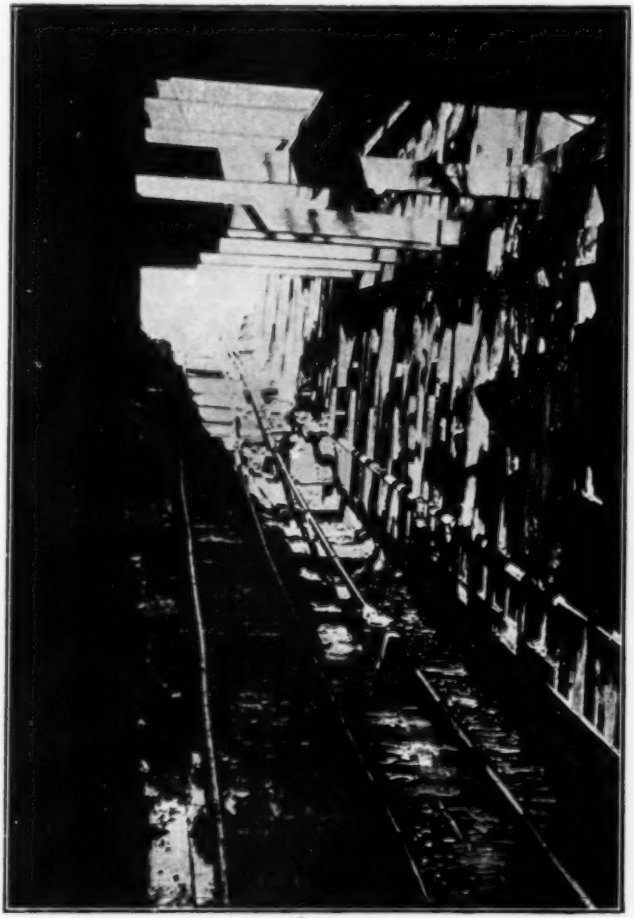


PLATE I.

VIEW OF TUNNEL UNDERNEATH MOUND AND CONCRETE SLAB.

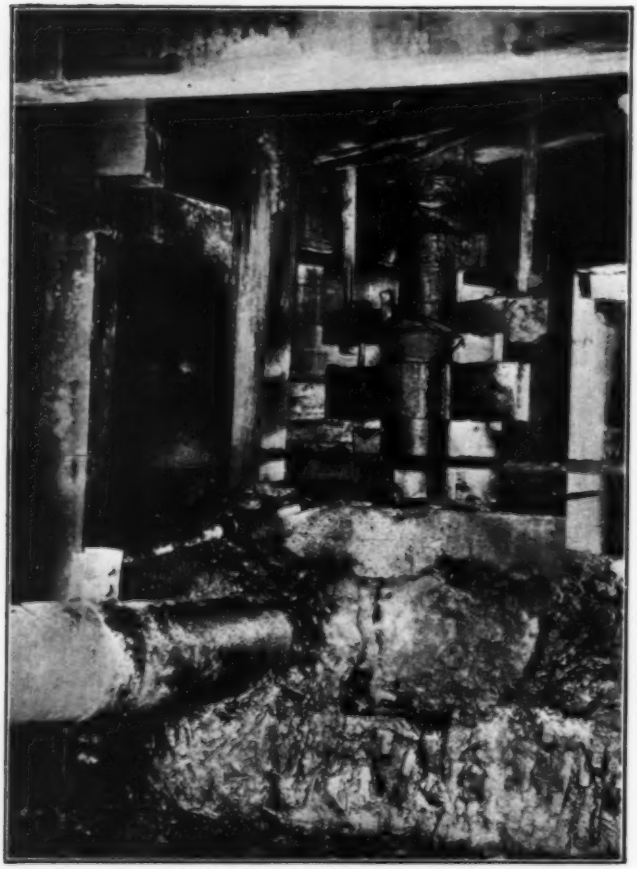


PLATE II.

VIEW OF UNDERSIDE OF "CONCRETE SLAB" SHOWING 16-IN. PIPE OF DRILLING-IN DEVICE

PLATE III.

VIEW OF WELL HEAD AFTER FITTING SPACER PIECE AND GUY RODS.

PLATE IV.

VIEW OF WELL SHOWING STOPPER GEAR AND WELL HEAD.

leaky flanges, the pressure would quickly dissipate, and leave only a small flow to be dealt with. Given the assurance that the plug was fixed in its position in the well-casing and would allow a flow of only a few hundred barrels daily, the situation would have been relieved of its alarming aspects. The saddle at "D" showed a pressure of only 65 pounds "closed in," and a flow of about 75 barrels daily. As it was not possible to know if the valve in pit "C" was entirely closed, a saddle was placed in front of this valve and showed a pressure of 275 lbs. with the saddle valve closed, and a production of about 200 barrels daily with the 2 in. valve open. Means for handling this additional oil were provided by sumps and pumps, but after flowing for 36 hours the saddle was plugged by bits of debris, presumably from the disintegrated cement plug. A third saddle was placed at "A," as near the supposed location of the well-head as was convenient, since it was thought that the horizontal run of pipe from "A" to "B" might contain further debris and repeatedly plug the saddle at "C," which would be less likely to happen to the saddle at "A." Before this last saddle could offer any test as to pressure, its gasket blew out and its 2-in. gate valve was blown off, and while repairs were being made, further debris plugged the outlet, but production from it in the interval was estimated at 2000 barrels daily. This was rather convincing evidence that there was more to deal with than simply an accumulation of pressure in the upper part of the well casing.

After so many vicissitudes, entailing changes of connections, which this well had suffered since it was first brought in, there was no great certainty felt as to the arrangement and condition of its fittings. Since it had been capable of producing as much as 40,000 barrels of viscous emulsion daily without being fully opened, there was no doubt that in the event of an accident the capacity of the well, in unrestricted flow of salt water, would have been so great as to be almost disastrous, as it would have been quite beyond the power of any equipment then in the fields to handle, and the damage caused before such equipment might become available would have been tremendous. It was thought probable that the slightest disturbance of the well-head fittings might precipitate such a disaster and, therefore, although it was of moment to carry through the work of closing the well with the greatest speed, rather elaborate plans were made in order to provide as far as possible against every contingency that could be thought of.

As the leaks from flanges and seepages amounted in the beginning to 200 barrels daily, convenient sumps were provided and the oil was pumped to storage. It is of interest to mention here that from the beginning to the end of the long operation of bringing this well under control, there was no sign of salt water or emulsion.

Three cuts were started at the periphery of the mound roughly 120 degrees apart, and were driven at ground level toward the centre until all met, where an additional space was cleared large enough to accommodate a 22-ft. base steel derrick, erected on old beams so disposed as to keep all additional load off the so-called concrete slab, whose weight was supposed to be reinforcing the holding down bolts of the capping device through the medium of guy rods radiating from the top of the well-head gear to the corners of the slab.

In the meantime two sloping cuts about 8 feet wide were started at ground level, both some 100 feet from the well-head, and nearly at right angles to each other. These cuts sloped sufficiently to expose at their junction the point of entrance of the milling cutter used in 1919, and, fortunately, this junction was at such level that water percolating through the gravel bed of the adjacent river, while always troublesome, did not become a great obstacle. As these cuts were driven under the supposed concrete slab, it was discovered that the original derrick floor (of 1910), although much sagged by the weight of the gravel above, was still in very good condition. The cuts, lagged and timbered throughout, became tunnels (Pl. I.) as they passed under the old derrick floor, and at each entrance fire doors, which could be closed from the surface, were installed, and two steam snuffer pipes were introduced into the fairly tight room thus formed, so that any ignition of the constantly escaping gas within this room might be dealt with, or any fire originating outside might by this means be prevented from reaching the well casing. A sprinkler system was installed throughout the length of both cuts, and Foamite extinguishers were stationed nearby. Fresh air helmets were also provided, so that rescue work might be possible if need should arise—which it frequently did—and a diver's airpump was installed to supply the helmets instead of the small blowers ordinarily used, which, although quite serviceable for very brief jobs, where only short runs of hose are required, have not been satisfactory under contrary conditions. Two steam air blowers of fairly large capacity for general ventilation, and fire hoses with a constant supply of high-pressure water, were provided. There was, of course, the ever present danger of the gas becoming ignited through accidental sparks, carelessness or malice of some disaffected workman, or lightning in the storm season, but by careful selection of staff and workmen the first and most probable dangers were greatly reduced, and by closing the fire doors and turning on the steam snuffers at the approach of, and during any storm, however slight, it was felt that the risk due to lightning was practically eliminated.

The two sloping cuts fully explored the under part of the slab, and the clearing away for the derrick disclosed the well-head

fittings, still covered, however, with the coke enveloping the reinforced concrete which had been placed around them; the only visible part of the fittings being the partly burned main clamp and the tops of the holding down bolts which were also very badly burned. A little further clearing away of fairly loose material exposed the upper flange of the top valve, entirely undamaged, as well as a short section of the holding down bolts under the clamps, which were also unhurt. (Fig. 2.)

Before this time it was seen that, except for very small leaks in the flanges and valves of the flow-line, all leakage was coming from below the slab, and, it was thought, almost certainly from the

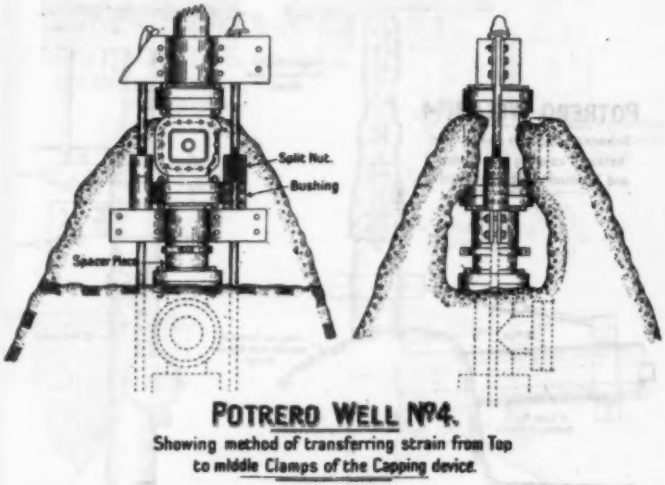

Split Nut.
Bushing
Spacer Piece
POTRERO WELL No4.
Showing method of transferring strain from Top to middle Clamps of the Capping device.

FIG. 2.

point of entry of the drilling-in device into the 13-in. casing. This was not absolutely settled until practically all preliminary operations were completed, as the junction of the 4-in. drill stem with the 13-in. casing was hidden, firstly by the 16-in. conductor pipe, which carried the 4-in. drill stem and the two 6-in. guide pipes, and abutted on the 13-in., and secondly by the original gravel and clay surrounding the two larger pipes. As the conditions at the point where the 4-in. drill stem entered the 13-in. casing were absolutely unknown, no further exploration of this point was made for it was feared that the leakage (which had increased abruptly, after the first few weeks from 200 bbls. to 1000 bbls. daily, and

then remained constant for months) was being confined to this amount by some debris from the former plugging, which debris might conceivably be released were the 4-in. stem to suffer any movement, however slight, and as the gravel had bedded the pipes for years and gave them rigid and positive position, it was thought better to continue in uncertainty as to the precise point and nature of the leak, rather than risk enlarging it greatly by removing the gravel. It was later discovered that this condition actually obtained, and that free of this debris the leak would have amounted to 10,000 to 15,000 bbls. per day.

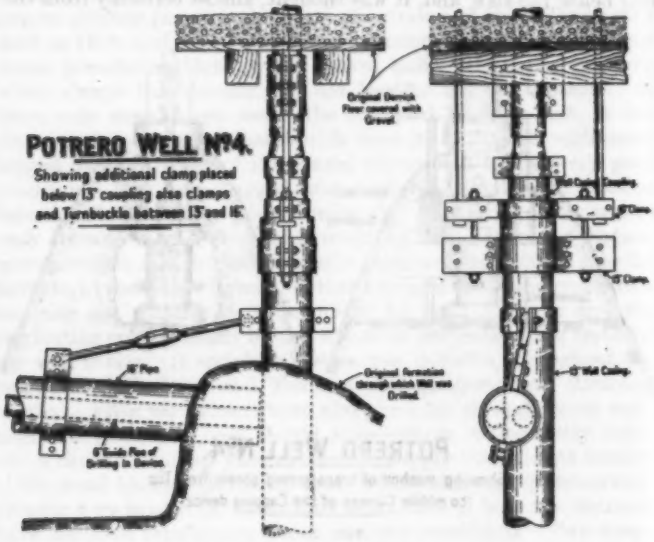

POTRERO WELL No4.
Showing additional clamp placed below 13" coupling also clamps and Turnbuckle between 13"and 16"
Original Derrick Floor covered with Gravel
Original formation through which Well was Drilled.

FIG. 3.

Fig. 3 shows the position of the 16-in. and 13-in. pipes, and the means taken to ensure that they should not move in relation to each other effected by the application of clamps and turnbuckles. Fig. 3 also shows the reinforcement of the old clamp on the 10-in. by a new one on the 13-in.; the 10-in. casing emerging from the 13-in., and being reduced to 8-in., and two smaller clamps put on in the early days probably to stop small leaks, and reinforce the joints. (Pl. II.)

At the time of starting the various cuts, the end of the drill stem furthest from the well, and which after the well was plugged

in 1919 had been encased in a block of concrete, was uncovered, showing all the arrangements in a good state of preservation. The 4-in. valve was slightly opened, showing oil and gas, and a gauge being applied, registered a pressure of 315 lbs., which later increased to 400 lbs.

As before stated, nothing could be seen or determined as to the state of preservation of the well-head gear above ground, except for the top clamp of the bell nipple device, and this clamp was greatly damaged by fire. On one side, the clamp's upper corners

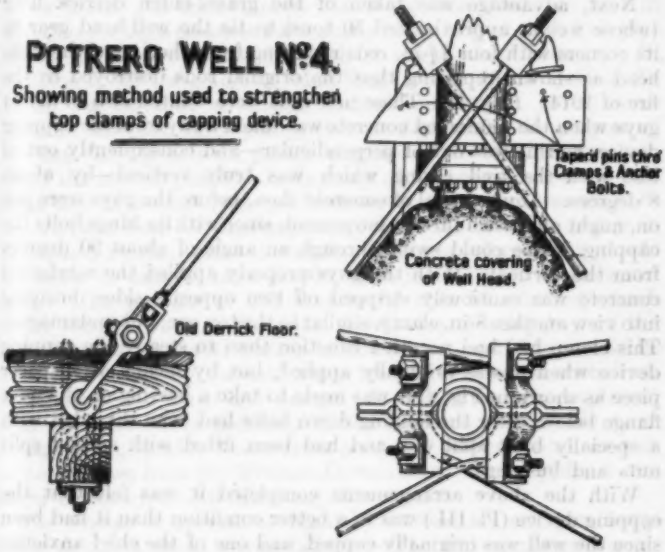

POTRERO WELL No.4.
Showing method used to strengthen top clamps of capping device.
Tapered pins thro' Clamps & Anchor Bolts.
Concrete covering of Well Head.
Old Derrick Floor.

FIG. 4.

had been melted off, and the holding down bolt on that side had lost its nut completely in the same manner. On the other side, while the bolt and nut were nearly intact, the nut had virtually no bearing on the clamp, and to all appearances the bolt had been stretched and its washer bent. So far as could be seen, and later investigation proved it to be the case, the covering of coke, together, with the hold of the corroded surfaces of the clamps on the bolts, and the tight fit of the bell nipple on the casing collar, prevented the well-head gear from being blown off, if the possible bond between the concrete surrounding the capping device and the supposed

concrete slab below be excepted. As it was presently discovered that this concrete slab was concrete in name only—it being actually nothing more than gravel piled on the old derrick floor and boxed in by boards on its edges—there could, of course, be no appreciable bond between the two objects.

The first operation of assuring that the clamp would not be blown off the bolts was to drill through each clamp and bolt and pin them together with a well fitting pin. This was accordingly done as indicated in Fig. 4, and every precaution was taken to cause as little vibration as possible while carrying out this operation.

Next, advantage was taken of the gravel-laden derrick floor (whose weight approximated 50 tons) to tie the well-head gear to its corners with four 1¼-in. rods radiating from the top of the well-head as shown, replacing thus the original rods destroyed in the fire of 1914. (Fig. 4.) These new rods were wanted also to act as guys when the reinforced concrete was taken away from the capping device, as this was out of perpendicular—and consequently out of line with the well casing which was truly vertical—by about 8 degrees. Any removal of concrete then, before the guys were put on, might allow still further movement, since with its hinge bolts the capping device could swing through an angle of about 90 degrees from the vertical. With the guys properly applied the reinforced concrete was cautiously stripped off two opposite sides, bringing into view another 8-in. clamp, similar to the top one, but undamaged. This clamp had had no other function than to steady the capping device when it was originally applied, but by means of a spacer piece as shown in Fig. 2, it was made to take a bearing on the next flange below, after the holding down bolts had been threaded with a specially built split die, and had been fitted with special split nuts and bushings.

With the above arrangements completed it was felt that the capping device (Pl. III.) was in a better condition than it had been since the well was originally capped, and one of the chief anxieties had by this means been removed. It is true that the short run of flow-line still connected to the well offered another possible avenue for disaster to overtake the subsequent operations, but as it was in a readily accessible position in case of any failure, nothing more than the clamping of some cracked flanges was considered desirable until a future stage of the operations would allow it to be entirely disconnected with less danger of disturbing the well.

While the measures already recounted were being taken, three pumps were set up some distance from the well, and so connected as to provide a most flexible arrangement. One pump was a 12 in. by 6¾ in. by 12 in., the second a 12 in. by 4 in. by 12 in., and the third a pump used in general plugging operations and

designed for high pressures; its dimensions were 12 in. by 2½ in by 10 in. The first pump was equipped with an eight-inch suction hose, and by transference of the hose could take its fluid from the pit dug in the ground near by or from a steel mud-mixing box alongside the pit and elevated somewhat above it. This box might also discharge into the pit, and it was by this means that the pit's supply was maintained. The second pump took its suction directly from the pit, or by the closing of its suction valve it might be thrown in series with the first, or low-pressure pump. The third or high-pressure pump took its suction from the high-pressure water lines. All three pumps had a common discharge, and in addition the high-pressure water pump had a loop of eight-inch pipe about 150 ft. long through which it might also discharge. In addition to the foregoing, a "Mud Hog" pump, 10 in. by 5½ in. by 12 in. was installed at a large mud pit on a small hill at some distance from the three pumps just mentioned, for the purpose of keeping the three main pumps supplied with fluid. Keeping in mind the always possible contingency of having to combat a very large flow of hot salt water, a fresh water connection was made to the well site from the discharge manifold of the main line pumps in the pump-station some hundreds of yards away. This made available in case of need 30,000 to 40,000 bbls. of fresh water daily. The purpose of this was to be able to substitute fresh water for salt water at the leaks should they develop beyond the capacity of the smaller pumps to counteract, and this was to be effected by pushing the salt water into the formation with fresh water from the main line pumps. It should be here explained that any salt water pollution of the adjacent river would have brought innumerable claims from land and cattle owners, as well as heavy fines from the Mexican Government. Fortunately, it was never necessary to call this pump into service.

The scheme of operations originally decided on, and practically never deviated from, was as follows:—The first operation was to pump into the well (through the old drilling-in device) a large volume of fresh water, notwithstanding the leakage of 1000 bbls. of oil daily. This was to be accomplished simply by pumping a great deal more water into the well than could find its way out through the leaks. The purpose of this water was threefold: first, to displace the oil in the casing, either by pushing it back into the formation, or due to the difference of the specific gravity, the water would find its way to the bottom and the oil in the casing would finally be "bled off" through the leaks—all depending on the speed with which the water might be pumped. Second, the casing, standing thus full of water instead of oil, would by its superior weight compared to a similar column of solid oil, exert more

back pressure against the natural pressure of the well (which approximates 1100 lbs.). Oil being easily aerated by gas, the latter does not readily rise through the oil to the top of the well where it may be dispersed; with water the opposite condition prevails—gas can form little or no froth or foam with water, and passes readily through it and may be "bled-off." Third, this fresh water, by displacing salt water known to be present at the foot of the well casing, and ridding the casing of gas, provided a good medium for the reception of the heavy mud fluid which was to follow the initial pumping of fresh water, as mud is readily "cut" or "aerated" by the presence of gas, and salt water quickly coagulates it, thus changing its character and usefulness.

The next operation was to pump large volumes of heavy mud fluid of a specific gravity of about 1·6 (this being the heaviest obtainable in this district) until a solid column of mud free from all gas was obtained in the well casing. As the well was something more than 1900 ft. deep, this column, if fully attained, would exert a "back pressure" on the porous formation below of more than 1300 lbs. to the square inch, or more than enough to counterbalance the pressure of the well. Once this superior pressure within the casing were achieved, it would only remain to learn by experimenting, how long this condition might be retained, as there was no doubt that such a column of mud, under the familiar conditions obtaining in wells in this district, would sooner or later be so "cut" by gas as to lose its efficacy. The chief obstacle in attaining such a solid column of mud was thought to lie in the position and nature of the plug of 1919, since it was felt that this plug or portions of it might be very porous and allow large volumes of upward flowing fluid to pass, but might promptly stop the passage of mud downwards. In such a case it was thought that either of two methods might be depended upon to overcome the difficulty thus presented. The first comprised the pumping in of mud as far as this operation might be safely carried, giving due consideration to the pressure the old casing and fittings might resist; then allowing the well to discharge this mud at a rate fast enough to bring up with it pieces of the old plug. This process might continue until the plug was so reduced or re-arranged as to allow the well to accommodate the desired quantity of mud. Failing this, and depending upon the quantity of mud that might be forced into the well—and the pressure necessary to keep it from flowing out—iron oxide in a finely pulverised form might be mixed with fresh mud to bring its specific gravity above 2·0, thus making effective a column of the mixture as short as 1250 ft. While nothing certain was known of the conditions within the casing, it was

thought that this latter proposal allowed a very fair chance for success.

Should it be determined by trial, however, that the pressure could not be overcome sufficiently for the well to remain quiescent for a time sufficient to effect the repairs contemplated, resort would then be had to some mechanical device whereby repairs might be carried out despite the well's pressure. Accordingly, while other preparations were being undertaken, a stopper-gear was made. This gear consists of a 6¼-in. pipe containing a 4-in. pipe, both of any convenient length, and so arranged and equipped that the 6¼-in. by being held stationary may be made to expand a lead packer carried by the smaller pipe, if the last named be drawn upwards while both are suspended in a well-casing. Fig. 5 shows the details of this device. It must, of course, be understood that appropriate clamps, bolts, etc., were provided for the insertion

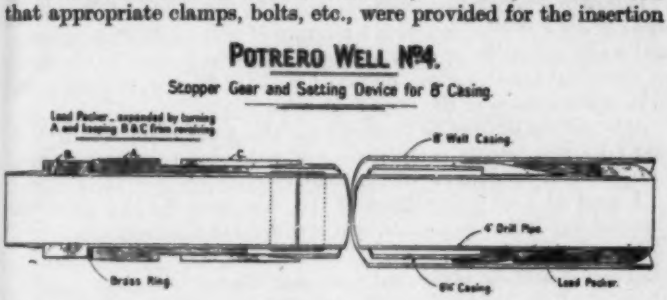

POTRERO WELL Nº4.
Stopper Gear and Setting Device for 8" Casing.
Lead Packer - suspended by turning A and keeping B & C from revolving
8" Well Casing.
4" Drill Pipe.
Brass Ring.
6½" Casing.
Lead Packer.

FIG. 5.

of this device under a heavy flow of fluid, and that a valve on the top of the gear was provided so that the well might be shut in once the packer was properly expanded against the walls of the casing.

The repairs contemplated were as follows :—The withdrawal from the 13-in., 10-in. and 8-in. casings of the milling cutter on the end of the 4-in. stem used in plugging the well in 1919 ; the abandonment of the 13-in. casing entirely (as there were but some seventy odd feet of this casing in the hole, it served no useful purpose) ; the patching of the holes in the 10-in. and 8-in. casing after withdrawal of cutter ; the placing of a 10-in. valve on the 10-in. casing and surmounting it with an 8-in. by 10-in. Bradenhead ; the extension of the 8-in. casing through this Bradenhead ; and, finally, the placing of an 8-in. valve on the extended casing.

In order that the stopper-gear might be introduced, if and when necessary, and expanded below the holes made by the milling cutter, it was necessary to change the capping device, since the one in

place would not only not admit the stopper-gear, owing to its inclined position, but also because the "bell-nipple," which formed its lowermost part, had a smaller internal diameter than the outside diameter of the unexpanded packer. A new and suitable capping device was therefore provided ready for use, while other preliminary arrangements were being made.

An abundant supply of heavy mud was obtained, about 60 tons of iron oxide were provided, quantities of chopped rope yarn, cement—in case of need—and lastly, some barrow loads of horse manure were placed near at hand. This latter material, proved very helpful in stopping leaks during the pumping-in period, and, together with the rope fibre, when introduced with heavy mud, enabled pressures to be maintained which, otherwise, would have been quickly dissipated.

Before pumping operations were begun, a test was made by filling some lengths of 8-in. line with a mixture of thin mud, horse manure and small quantities of chopped rope. After standing for ten days no appreciable settling was observed, and the fibre was found to be held in suspension in the mud fluid.

After all the devices to be used had been made ready and tested, and all arrangements completed, it was decided to start pumping into the well on January 25th, 1926.

A good idea of the progress of the work may be had from the detailed log of the operations, and a portion of it is here quoted :—

8.12	a.m.	Tested out pumps and made final check.
8.37	,,	With well pressure standing at 350 lbs., started pumping water with No. 2 pump 500 lbs. pressure, 27 revolutions per minute, 4 in. liners.
8.38	,,	Leak at milling cutter almost entirely shut off.
8.44	,,	Pumping at 34 revolutions, 600 lbs. pressure.
8.50	,,	Leak at milling cutter increased and then almost stopped.
8.53	,,	Pressure 650 lbs., 29 revolutions.
8.56	,,	Pressure 500 lbs., 30 revolutions.
9.00	,,	Water flowing from 2-in. saddle on old 8-in. flow-line, valve has not been closed in order not to build up pressure on old well head fittings.
9.03	,,	Pressure 550 lbs., 31 revolutions.
9.07	,,	Pressure 530 lbs. started leaking water, oil and gas, between flanges on 8-in. flow-line ell.
9.28	,,	Pressure 575 lbs., 30 revolutions.
9.34	,,	Flow through 2-in. saddle from old 8-in. flow-line estimated at 600 bbls. per day, leak from between flanges 100 bbls. per day.
9.39	,,	Pressure 540 lbs., 34 revolutions.
9.46	,,	Leak increasing around milling cutter.
9.51	,,	Pressure 550 lbs., 35 revolutions.
10.10	,,	Pressure 550 lbs.
10.17	,,	Flange and saddle leaks increasing slightly.
10.24	,,	Pressure 540 lbs., 51 revolutions.
10.32	,,	Leak increasing at milling cutter, water and oil.
10.35	,,	Leaks from flanges and saddle estimated at 1500 bbls. per day.

10.45 a.m. Leak coming from under ground at point where old 8-in. flow-line enters the ground away from well.
10.52 ,, 8-in. flanged valve on tee in well-head leaking from bonnet.
10.55 ,, Pressure 575 lbs.
11.12 ,, Started No. 3 pump to force mud and manure into well through 8-in. line, stopped pumping water with No. 2 pump. Pressure 430 lbs.
11.13 ,, Pressure 380 lbs.
11.15 ,, Flange leaks on old 8-in. flow-line stopped. 2-in. valve on saddle closed. Underground leak at end of 8-in. flow-line stopped.
11.16 ,, Leak at milling cutter stopped. Leak from valve bonnet stopped.
11.17 ,, Pressure 390 lbs.
11.18 ,, Stopped pumping plugging mixture.
11.19 ,, Mixing mud with No. 1 pump and started pumping mud into well with No. 2 pump. Pressure 600 lbs., 20 revs.
11.25 ,, Small leak started at flanges.
11.27 ,, Pressure 600 lbs., 20 revolutions.
11.49 ,, Small leak at milling cutter.
11.50 ,, Pumping in mud and manure mixture.
11.55 ,, Stopped pumping mud and manure mixture.
12.00 noon. Pressure 550 lbs., 25 revolutions.
12.05 p.m. Slowed down pump to 17 revolutions. Pressure 550 lbs.
12.07 ,, All leaks stopped with the exception of a small leak between the flow line flanges.
12.21 ,, Pressure 600 lbs. Flange leak shut off. Increased pump to 25 revolutions.
12.45 ,, Pressure 610 lbs., 25 revolutions.
12.57 ,, Leak started between flow-line flanges.
1.06 ,, Pressure 600 lbs., 21 revolutions.
1.08 ,, Pressure 575 lbs.
1.35 ,, Pressure 600 lbs., 29 revolutions.
1.44 ,, Stopped pumping to go through valves of No. 2 pump.
1.55 ,, Started No. 2 pump.
2.08 ,, Pressure 600 lbs.
2.10 ,, Leak started at milling cutter.
2.11 ,, Leak at milling cutter increasing.
2.20 ,, Pressure 560 lbs., 19 revolutions.
2.50 ,, Pressure 550 lbs., 20 revolutions.
2.55 ,, Leak increasing around milling cutter.
3.02 ,, Stopped pumping mud.
3.03 ,, Started pumping mud and manure mixture. 600 lbs. pressure, 19 revolutions.
3.10 ,, Leak at milling cutter shut off. Pressure 625 lbs., 19 revolutions.
3.35 ,, Small leak started at milling cutter.
3.53 ,, Small leak started at flow-line flanges.
4.02 ,, Pumped in manure with No. 2 pump for one minute.
5.15 ,, Small leak started at milling cutter.
5.16 ,, Added manure to mud in No. 2 pump suction.
5.23 ,, Pressure 625 lbs., 16 revolutions.
5.50 ,, Pressure 580 lbs., still small leak at milling cutter.
7.23 ,, Leaking pure mud at milling cutter, pumped in manure for two minutes and stopped leak.
8.30 ,, Arranged to keep pumping all night holding pressure at 600 lbs., and slowing down pump if pressure rose. At 6.00 a.m. next morning pressure was 600 lbs., at 6 revolutions. Small leaks started periodically around the milling cutter but they were shut off in from one to five minutes by adding manure to the mud being pumped. Sp. gr. of mud pumped during day and night between 1.35 and 1.40.

January 26th, 1926.

7.00 a.m. It was decided to test out the well to see what effect the mud pumped had on the pressure. The well was left shut in, the pressure standing at 400 lbs., while the 8-in. line was cleaned out and refilled with a new batch of mud and manure. Pumps were gone over and a new batch of mud mixed ready to be pumped into the well.
1.44 p.m. The closed in pressure remains at 400 lbs.
1.45 ,, Opened up valve to bleed off well.
1.46 ,, Pressure dropped to 250 lbs. Well closed in and pressure rose to 290 lbs. Mud bled off badly cut by gas.
1.48 ,, Opened valve to bleed again. Pressure dropped as cut mud was bled off.
2.05 ,, Valve opened a little more and pressure went to 145 lbs.
2.12 ,, Valve closed and pressure rose to 170 lbs. in 4 minutes.
2.17 ,, Bleeding well, making cut mud and now and then a pocket of gas, as valve was opened pressure dropped until pressure was 90 lbs.
2.45 ,, Still bleeding well, pressure down to 70 lbs.
2.53 ,, Closed in well—pressure 125 lbs.
2.56 p.m. Started pumping mud and manure.
3.00 ,, Milling cutter leak stopped. Pressure 140 lbs. when pump stopped.
3.10 ,, Gas leak around milling cutter.
3.12 ,, Pressure had dropped to 55 lbs. through gas escaping.
3.13 ,, Pumped in mud and manure.
3.15 ,, Leak stopped, pressure standing at 150 lbs. when pump was shut down.
4.15 ,, Bleeding well.
4.19 ,, Pressure down to 20 lbs., well making gas cut mud.
4.20 ,, Closed in well.
4.22 ,, Pressure 180 lbs. Leak started in old 8-in. flow-line flanges. Pumping mud and manure.
4.25 ,, Leak stopped. Started pumping mud.
4.31 ,, Pressure 340 lbs. Leak started around milling cutter.
4.33 ,, Stopped mud pump and started pumping mud and manure.
4.35 ,, Pressure 230 lbs.
4.36 ,, Stopped mud and manure and started pumping mud.
4.38 ,, Pressure 270 lbs.
4.40 ,, Leak at milling cutter shut off, stopped pumping mud.
4.50 ,, Pressure 270 lbs.
5.08 ,, Started pumping mud slowly, with manure added slowly through suction.
5.40 ,, Pressure 4.20 lbs., 6 revolutions.
8.30 ,, Pump stopped and well closed in at 400 lbs. pressure.
6.00 a.m. Next morning the pressure had dropped to 375 lbs. No leaks around milling cutter during the night.

The log for January 25th and 26th is an example of what went on at the well for the next twenty days.

On the whole, the well was pumped to as high a pressure as possible without blowing out at the milling cutter, or, if a leak did start, it was stopped with mud, manure and chopped rope.

The following procedures were tried: holding the pressure between 400 and 450 lbs.; pumping up to between 400 and 450 lbs., and stopping until the pressure dropped to 375-350 lbs., and then pumping up again; leaving the well shut-in for a day or two to see if the mud would settle; bleeding off the gas-cut mud, and replacing

it with fresh at short intervals;* lengthening the intervals to see if more gas-cut mud could be got out.

The net result was that, although the well was perhaps a little quieter than it was when pumping started, it was far too active to consider changing the bell nipple, except at the probable cost of allowing unrestricted flow during the operation, which was to be avoided if possible.

Although it was estimated sufficient mud had been pumped into the well to fill it almost twice over, there was doubt as to how much was actually in the well, and how much had leaked past the milling cutter and between the old flow-line flanges.

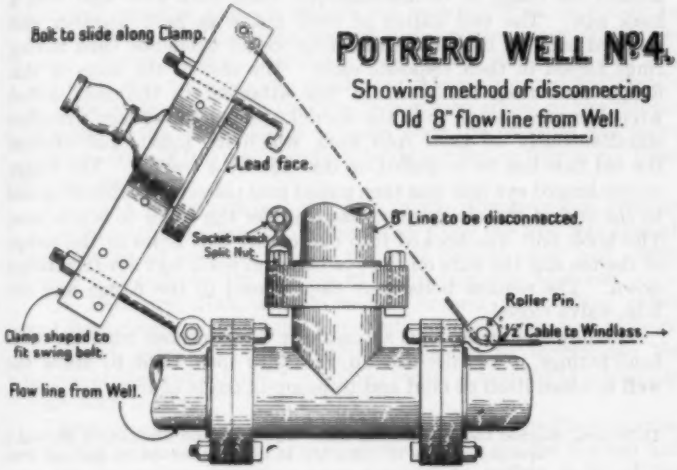


FIG. 6.

It was still not thought wise to disturb the end of the 16-in. pipe to investigate the leak around the milling cutter, although this leak was proving the greatest obstacle to getting sufficient mud into the well, but it was thought advisable at this stage to disconnect the old 8-in. flow-line as the various leaks in its flanges were also a great hindrance.

The disconnecting of the flow-line at a convenient flange nearest the well-head, and the placing of a reducing flange and valve in the place of the disconnected part, were therefore carried out as follows, and as shown in Fig. 6.

It was decided to disconnect the flow-line at a flange where it branched off a tee piece.

Two bolts were replaced on the flanges at each end of the tee by 1¼-in. eye bolts; a 2½-in. eye bolt was hinged between one pair of them and a roller placed between the other pair; an 8-in. flange, faced with lead, was connected to a 3-in. gate valve by a swedge nipple; a clamp was shaped and made up on the 2½-in. eye bolt hinged between the bolts already referred to, the opposite ends of the clamps were left parallel in order that a hook bolt could be slid lengthwise between them; the swedge nipple was left fairly loose in the clamps, in case it was necessary to turn the 8-in. flange to centre up the bolt holes.

Four nuts were removed from their bolts at equal distances around the flange to be disconnected, these nuts were split with a hack saw. The two halves of each nut were held together and screwed back on their bolts with four socket wrenches, each having rings forged in their opposite ends. The rest of the bolts of this flange were then removed. A line attached to the four socket wrenches and passed over the derrick, pulled the socket wrenches simultaneously off their split nuts, which fell apart, and allowed the old flow-line to be pulled on one side by a tractor. The flange on the hinged eye bolt was then pulled into place by a cable attached to the end of the clamp and passed under the roller to a windlass. The hook bolt was hooked into one of the bolt holes in the flange of the tee and the nuts on the eye bolt and hook bolt were tightened down. The regular bolts were then placed in the flange and the 3-in. valve closed.

The flow-line being thus successfully disconnected from the well-head fittings, it was decided on February 15th, 1926, to allow the well to clean itself of mud and to pump in oxide of iron.

11.00 a.m. Started bleeding off the well. The first mud discharged showed a specific gravity of 1.35, but it quickly turned to gas cut mud and at
11.31 „ showed the water that had first been pumped into the well.
12.15 p.m. Started leaking at milling cutter.
12.17 „ Nothing but fresh water coming out of well, the bleeder was closed and mud and manure pumped in to stop leak at milling cutter.
12.18 „ Leak stopped. Started pumped mud and oxide of iron s.g. between 1.9 and 2.05, pressure 350 to 450 lbs. per sq. in.
12.25 „ Started leaking at milling cutter. Estimated rate 10,000 bbls. per day.
12.28 „ Pumped in mud and manure, leak stopped.
12.42 „ Started leaking at milling cutter but stopped at once.
12.57 „ Started leaking at milling cutter, pumped in mud and manure.
1.01 „ Leak stopped. Pumping in oxide of iron at 350 lbs. pressure.
1.38 „ Started leaking at milling cutter. Estimated rate 15,000 bbls. per day. Started pumping mud and manure but this mixture also blew out at the milling cutter. Broken coke, chopped rope and dry paper were then added until the leak finally stopped at 1.54 p.m.

1.55 p.m. Pumping oxide of iron at 350 lbs. pressure.
4.10 ,, Started leaking at milling cutter, estimated 5000 bbls. per day. Pumped manure, leak stopped.
5.04 ,, Another 5000 bbls. leak stopped.
5.50 ,, Another 5000 bbls. leak stopped.
6.00 ,, Pumping stopped and pressure went to 300 lbs. It was decided to stop pumping for the night and stand by prepared to stop any leak that might start.

On February 16th pumping was started again in the morning. The pressure almost immediately rose to 500 lbs. and a leak started at the milling cutter. It was, however, stopped with mud and manure. With the oxide mixture leaking past the milling cutter, it was very difficult to keep an accurate gauge of the amount of oxide pumped into the well, or rather, the amount of oxide remaining in the casing, and the leaks seemed to be getting more difficult to stop. It was decided, therefore, to pump the well up to 475 lbs., and then stop the pumping until the pressure dropped sufficiently to allow resumption. In this way 5 feet were added to the column of oxide in the well on each occasion after the pressure had fallen between 50 and 100 lbs., pumping being carried on five or six times during the day.

Pumping was continued day and night, whenever the pressure fell sufficiently to allow it. About twice a day the well was opened, and the small amount of gas, oil- and gas-cut mud and oxide, which had collected in the top of the casing was bled off.

On February 27th, a leak started around the milling cutter and flowed with considerable force until stopped with mud, manure, rope and coke. It was thought advisable to investigate the source of the leak around the milling cutter, provided this could be done with safety.

The loose gravel through which the leaking oxide had been coming was dug away exposing the end of the 16-in. pipe for the top half of its circumference. This pipe reached to within 6 in. of the 13-in. casing.

The end of the 6-in. pipe containing the 4-in. drill-pipe of the milling cutter was flush against the 13-in. casing, top and bottom, and open at the sides about $\frac{3}{4}$ in. The 13-in. casing was found to be split longitudinally for a distance of $6\frac{1}{2}$ in. above and 5 in. below the $4\frac{1}{2}$-in. hole milled through it. One side of the casing had bulged out until it was apparently stopped by the end of the 6-in. pipe against it. The appearance of the split suggested, at the time of its discovery, that it was caused by the internal pressure rather than by the milling cutter. This was confirmed it was thought, by the fact that the bottom half of the 16-in. and 6-in. pipes and the gravel surrounding the 13-in. was completely filled with cement grout. It will be remembered that, when the

well was originally plugged, the greatest pressure reached—700 lbs. per sq. in.—was at the termination of pumping cement grout.

As there was no way of telling whether or not the 10-in. casing was also split, it was considered too dangerous to dig the cement away from around the 13-in. casing and the end of the 16-in. pipe in order that the latter could be cut off and a split tee placed around the 13-in. casing and the milling cutter. However, to provide a solid backing for the fibrous material pumped into the well, dry paper was firmly tamped into the end of the 6-in. pipe containing the 4-in. drill-stem and into the 16-in. pipe in the channels cut in the cement grout by the leak. The paper was in turn held in place by wedges and the whole covered with gravel and clay. It was hoped that the paper, providing the wedges prevented its blowing out, would become saturated and swell sufficiently to form a substantial backing for the mud and manure around the milling cutter. Pumping was continued, with pressures up to 550 lbs. with no leaks of any consequence.

By continually bleeding off the small amount of gas collecting, and holding the pressure between 400 and 500 lbs. with the pumps, a small amount of oxide was added to the column in the well each day.

The following shows the estimated amount of oxide subsequently pumped (expressed in lineal feet of 8-in. casing filled) the total amounting to 850 ft. In all some 67,000 lbs. of oxide had been pumped into the well :—

	ft.		ft.		ft.		ft.
Mar. 1, 1926,	6	Mar. 6, 1926,	10	Mar. 11, 1926,	20	Mar. 16, 1926,	160
„ 2, „	3	„ 7, „	5	„ 12, „	28	„ 17, „	140
„ 3, „	4	„ 8, „	5	„ 13, „	60	„ 18, „	60
„ 4, „	3	„ 9, „	6	„ 14, „	80	„ 21, „	25
„ 5, „	5	„ 10, „	20	„ 15, „	150	„ 24, „	60

On March 25th the valve was opened on the milling cutter drill-stem and with the exception of a small amount of gas that quickly became exhausted, the well remained dead for the hour and a half the valve was left open. It was two months since pumping in to kill the well had been started.

At this point, it was considered safe to change the bell-nipple and the well was pumped up again while the guy rods were taken off. All pressure was bled off the well and the chain binders and anchor bolts removed. This left the old capping device free to be lifted off.

The bell-nipple had a considerable friction hold on the 8-in. coupling but was lifted clear without difficulty. There was a puff of gas, and the oxide was found to be standing about 5 ft. down the well. The new capping device could have been swung immediately

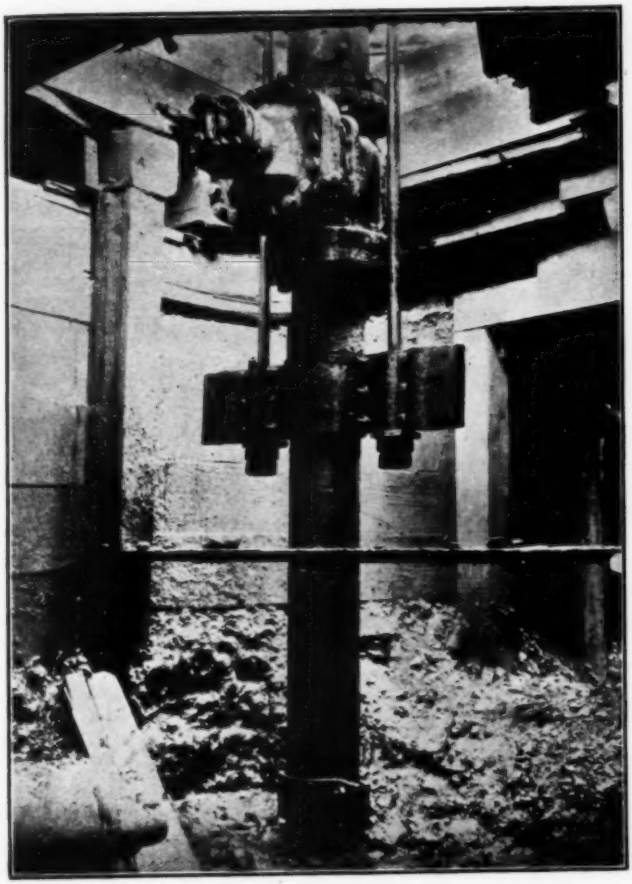


PLATE V.

VIEW OF LOWER PORTION OF WELL HEAD AFTER CLOSING-IN OPERATIONS COMPLETED.

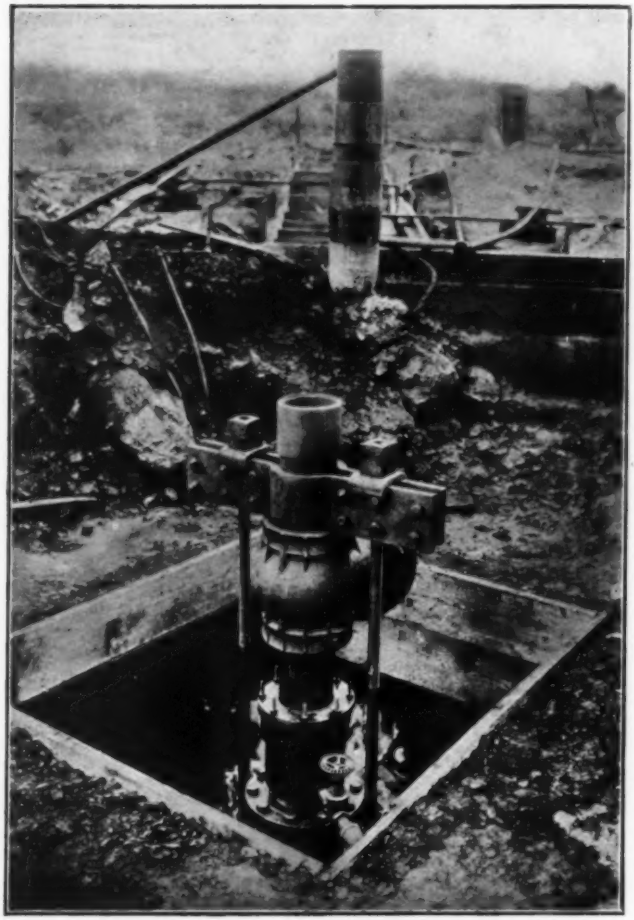


PLATE VI.

VIEW OF UPPER PORTION OF WELL HEAD AFTER CLOSING-IN OPERATIONS COMPLETED.

into place and the entire change made within four minutes, but as the well was quiet, the distance from the bell-nipple to the top of the 8-in. casing was measured and the coupling, from which the old capping device had been removed, was cleaned with the idea that a die-nipple and 8-in. valve might be screwed directly into it. It was found, however, that the 8-in. coupling had been swaged in by the bell-nipple until its inside diameter, at the top, was about the same as the 8-in. pipe. The new bell-nipple was accordingly placed on the well, the oxide having risen to within a foot of the top during the eight minutes the well was standing open.

After the capping device had been changed, the well was considered dead enough to permit the use of an oxy-acetylene cutting and welding torch. Therefore, on March 26th, the 16-in. pipe was cut off and split lengthwise into two halves, with the torch, in order to remove it from around the two 6-in. pipes; likewise, the 6 in. was cut off and split from around the 4-in. milling cutter drill-stem. The second 6-in. pipe was also cut off, thus nothing remained but the 4-in. drill-stem and a short piece of 6-in. which was left around the 4-in. and against the 13-in. casing. The next day this piece of 6-in. was cut away with the torch, the 13-in. casing was cut off above and below the hole drilled through it, split, and removed in two halves. A friction clamp was placed on the 10-in. casing to be dropped down over the hole when the milling cutter had been withdrawn. In the meantime screwjacks had been placed against the drilling-in device of the milling cutter to withdraw the drill-stem, but when the 13-in. had been cut away, it was found that the drill-stem had collapsed and the milling cutter gone. The 4-in. drill pipe was, therefore, cut off with the torch, withdrawn, and the friction clamps slid down over the hole and bolted up. The well was then pumped up to 500 lbs.

It is probable that when the milling cutter finished cutting the 8-in. casing, the well pressure forced one of the pieces cut out back through the drill-stem into the side opening, causing it to lock, and further rotation split the end of the drill-pipe, allowing the milling cutter to be carried off through the flow-line or be pumped down the well.

On March 28th the stopper gear (Pl. IV.) was set 7 ft. below the holes drilled through the 8-in. and 10-in. casings and the 8-in. pumped up to 600 lbs. On the 30th an experienced welder was obtained to patch the holes. The clamps were removed from the 10-in. casing, and it was found that the stopper gear had sealed the 8-in., but there was a small amount of gas and oxide flowing from between the 8-in. and 10-in. A 1-in. hole was drilled in the 10-in. casing, about a foot below the hole to be patched, and was threaded with a bolt tap. Between the 8-in. and the 10-in. casings and

around the holes in them, asbestos packing was placed, thus sealing off the part to be welded while the small amount of oxide and gas continued to flow away from the 1-in. hole in the 10-in. The milled hole in the 10-in. was cut out to 6½-in. in diam., thereby allowing an inch of space for welding around the hole in the 8-in. A patch, cut from a joint of 8-in. casing, was welded in place, and, in a like manner, the 10-in. was welded. During this time the gas, coming from the 1-in. hole in the 10-in., was kept burning in order to be sure that none would collect in the tunnel and form an explosive mixture. When the casings had been patched, a bolt was screwed into the 1-in. hole, welded to the pipe and cut off.

The stripping off of the old connections, the screwing of a new nipple into the 8-in. casing, and the placing of the new valves over the stopper gear, presented no difficulty. The patches in the casing and the well-head connections were tested to 650 lb. A clamp was placed over the patch in the 10-in. casing for added safety, although it was hardly necessary.

After everything had been tested, the stopper gear was pulled (Pl. V. and VI.) and bailing the oxide from the 8-in. begun. When the well had been bailed down 500 ft., water was added to the well as fast as the oxide was bailed from beneath it, in order that collapsing stresses might be kept off the 8-in. When the oxide was standing at 1300 ft. and the water level at 500, the well was allowed to stand closed in for an hour. When opened the water level was within 20 ft. of the top of the casing. The bailer was run in 100 ft. and withdrawn as rapidly as possible; when this had been done several times the well began to flow. The 8-in. valve was closed and a swedge and 3-in. valve placed on top of it, a 3-in. leadline was laid for 100 ft. away from the well. The 8-in. valve was opened and the flow controlled by the 3-in. valve. All the oxide was blown out of the well, as well as a considerable amount of formation. Finally the oil came clean and the well was closed in —April 10th, 1926.

The work carried out in closing this well was in its first stages under the general directions of Mr. A. T. Beazley, M.Inst.P.T., assisted by Mr. R. H. Ames, M.Inst.P.T. The latter succeeded Mr. Beazley and remained in direction of this work until its completion. Mr. J. C. Fortune was Resident-Superintendent throughout the work and the authors are largely indebted to the use of his notes for help in preparing this paper.

Mr. John W. Westcott, driller, acted as foreman from the beginning until the successful conclusion of the work.

The authors are indebted to Mr. J. B. Body, Director of the Mexican Eagle Oil Co., Ltd., for permission to publish this paper.

A Pipe Still for Continuous Distillation in the Laboratory, and some Results obtained from it.

By A. A. Ashworth, M.A., A.M.Inst.C.E. (Member).

While studying the design of pipe stills for continuous distillation in the refinery, it was manifest to the writer that the temperature range occurring in a pipe still distillation, where, as in the Trumble system all the light oil vapours are taken off together, must be very different from that occurring in a bench of the usual type of shell stills; yet no records were obtainable from current literature from which the required information as to the magnitude of this difference could be obtained and no writer on the subject had even made the slightest reference to the point. The amount of the difference was difficult to calculate, but some not very direct calculations made by the writer indicated that the temperature at which the light oils were vaporized in a pipe still such as the Trumble would be some 80° to 100° C. below the temperature necessary for the same distillation in the usual bench of continuous crude stills, the difference naturally depending on the distillation characteristics of the crude oil, a difference sufficiently large to be of great importance when designing the residue and vapour heat interchangers which are essential parts in economic crude oil distillation and too great to be accepted without further proof.

With a view to confirming the results arrived at by calculation, a form of laboratory pipe still was devised which has proved in practice to give reliable and consistent results and which may well be of use in other experimental work than that for which it was primarily designed.

The requirements to be met by the laboratory still were that it should be capable of continuously distilling the light oils from a crude oil up to a temperature of about 300° C. and with a rate of feed of from 7 to 10 c.c. per minute. With this rate of feed, it would be possible to obtain a fairly full range of distillation temperatures and percentages without using up an inconvenient amount of crude oil. It was also essential that the temperatures of both oil and vapour should be obtainable with considerable accuracy.

The design arrived at is shown in Diagram No. 1.

The crude oil is fed in at the desired rate into the funnel shown and fills the vertical tube to a point high enough to maintain

the flow through the rest of the apparatus. From this vertical tube it enters the inclined tube in which is inserted an electric heater. The internal diameter of the inclined tube is $\frac{5}{8}$ in. The electric heater consists of a $\frac{1}{4}$ in. external diameter tube extending the full length of the inclined tube and through which passes one lead of the electric circuit. The outside of the $\frac{1}{4}$ in. tube is wound with 31 ft. of 0·012 in. dia. nichrome wire having a resistance of 5·2 ohms. per ft. at atmospheric temperature and of 5·5 ohms. per ft. at 300° C. This heater was designed for use with a 220 volt D.C. circuit and was proportioned to pass a current of about 1·3 amperes at 300° C.

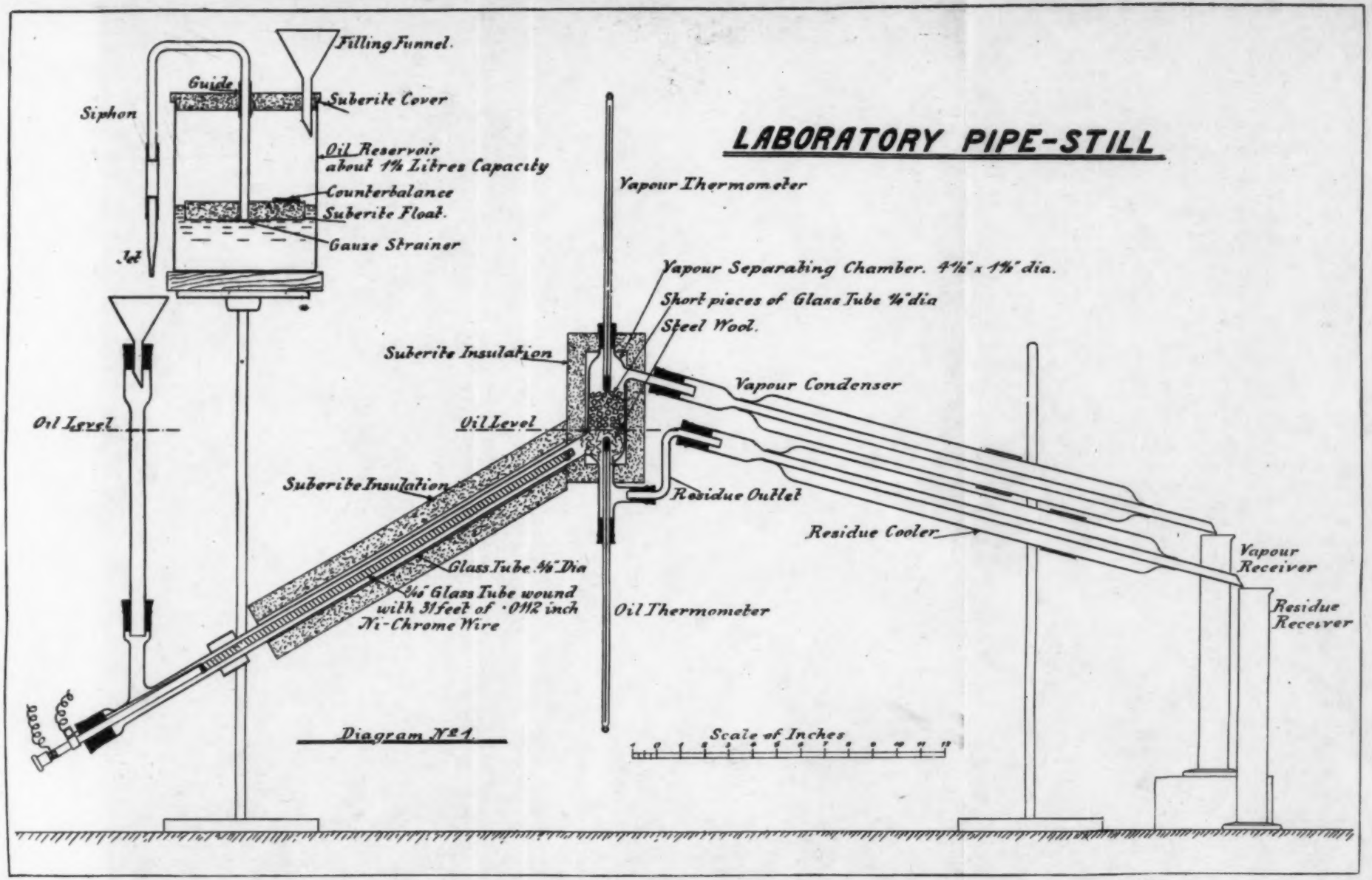
From the inclined tube, the oil and vapour enter a separating chamber which is $1\frac{1}{2}$ in. dia. by 4 in. high in the body. At the top of the chamber is a neck through which the thermometer for taking the vapour temperature passes and at the bottom another neck through which passes the thermometer for taking the oil temperature and from which neck the undistilled oil passes by means of a bent tube to the Liebig condenser which serves to cool the oil on its way to the graduated measure which ultimately receives it.

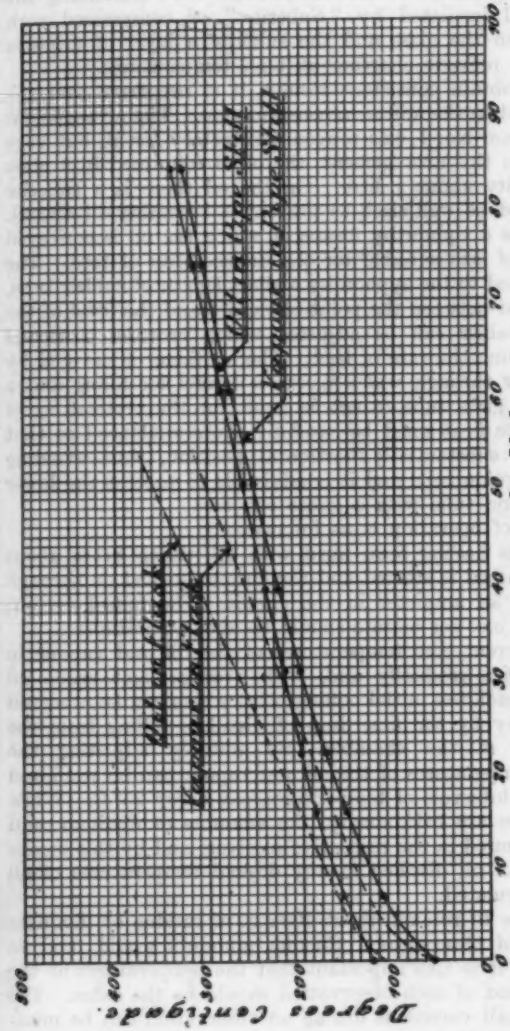
The vapours leave the chamber by the upper branch and are condensed in a Liebig condenser and delivered to another graduated measure.

The body of the separating chamber is filled with $\frac{1}{4}$ in. glass beads resting on a small support of steel wool to just below the level of the bulb of the upper thermometer. These beads serve to prevent oil from foaming up in the chamber and reaching the vapour thermometer and vapour outlet.

The level of the oil in the chamber is kept at the desired point by the dimensions of the siphon tube through which the residue passes to the cooling condenser.

With this arrangement, the vapours are kept in continual and intimate contact with the oil so that equilibrium can be attained and the temperatures of both oil and vapour are measured immediately after separation. It is important that these two conditions be realized in order to give conformity with the conditions in a commercial pipe still. In the laboratory apparatus it is comparatively easy to get the oil temperature correctly, but the vapour is very speedily affected by radiation losses and, in earlier attempts where these losses were not sufficiently guarded against, results obtained showed considerable discrepancies. With the arrangement shown, the discrepancy disappears and there seems no difficulty in duplicating results. The separation between the oil and vapour seems very complete and the distillates obtained showed an unusual absence of colour.


LABORATORY PIPE-STILL
Filling Funnel.
Guide
Siphon
Suberite Cover
Oil Reservoir
about 1½ Litres Capacity
Counterbalance
Suberite Float.
Gauze Strainer
Lid
Vapour Thermometer
Vapour Separating Chamber. 4½" x 1½" dia.
Short pieces of Glass Tube ¼" dia
Steel Wool.
Suberite Insulation
Vapour Condenser
Oil Level
Oil Level
Suberite Insulation
Residue Outlet
Residue Cooler
Vapour
Receiver
Glass Tube ⅜" Dia
⅛" Glass Tube wound
with 31 feet of ·0112 inch
Ni-Chrome Wire
Oil Thermometer
Residue
Receiver
Diagram No 1.
Scale of Inches


Degrees Centigrade.
100
200
300
400
0
10
20
30
40
50
60
70
80
90
100
Percentage by Volume
Distillation of Pennsylvanian Crude. Sp. Gr. 0·815.
Diagram No 2.

The separating chamber and the inclined tube containing the heater are well insulated by "Suberite" or compressed cork casing. Between the glass and the suberite a layer of asbestos is advisable to prevent charring at high temperatures.

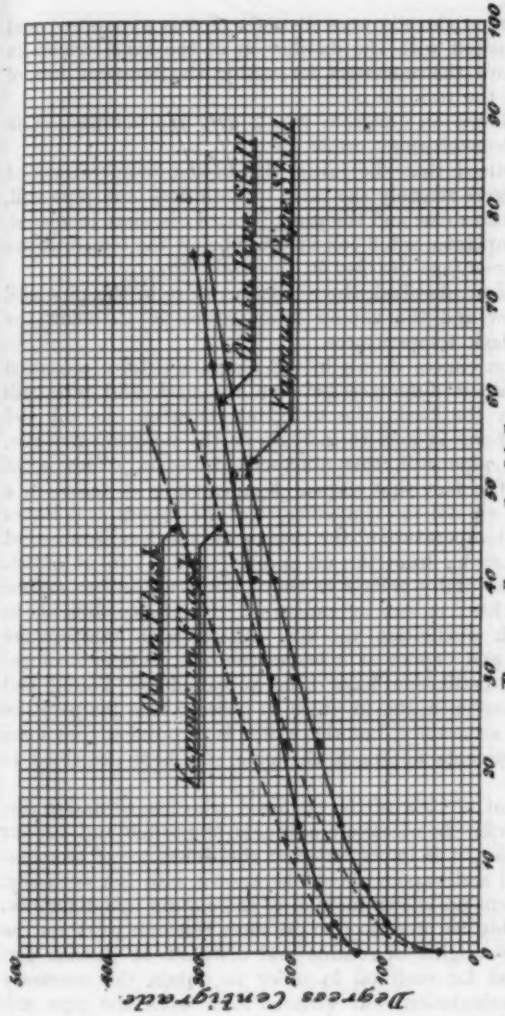
In order to obtain consistent results, it is necessary that the oil should be fed to the still at a constant rate. The arrangement shown in Diagram No. 1, has proved satisfactory for all but very viscous oils. In this arrangement, the oil is contained in a glass vessel of capacity about 1 litre. On the oil there is a suberite float which must be well sized to prevent it becoming oil soaked. The float carries a siphon by means of which the oil is conveyed to a glass jet of size suitable for the desired rate of feed. The jet being attached to the syphon by a short length of rubber tube, the vertical head between the point of the jet and the level of the oil in the container can be adjusted which provides a second means of adjusting the rate of feed. The container is covered by a suberite cover through which passes a funnel for filling and a short length of glass tube to act as guide for the vertical leg of the siphon. The float must be carefully counterbalanced so that it maintains a substantially horizontal position, thus avoiding friction in the guide tube and it is advisable to protect the lower end of the siphon tube with a gauze strainer.

The method of operation is as follows:—

The apparatus having been filled with oil, which takes about 150 c.c., the oil feed is started and the current turned on through a rheostat and an ammeter in the circuit. The initial current for a feed of 10 c.c. per minute should be about 0·5 ampere.

With this current, the temperatures of the oil and vapour in the container rise gradually and, with average light crude oil will gradually reach the initial boiling point which can be observed in the usual way by the first drop of distillate falling from the vapour branch of the chamber. By suitably adjusting the rheostat, the temperatures of the oil and vapour can be stabilized at the required intervals of temperature, say every 25° C. While the temperatures are held steady, the amounts of distillate and residue are measured in the respective receivers and by this means the percentage of oil distilled at any desired temperatures of oil and vapour calculated.

It is advisable to run off about 100 c.c. of residue or distillate at each point of observation. Smaller amounts would tend to inaccuracy, and it is also important that the temperatures at the beginning and end of each observation should be the same. The effect of any small variations during an observation can be minimized by taking the mean temperatures without introducing serious error so long as these variations do not exceed 2° or 3° C.



Distillation of Mid-Continent Crude. Sp. Gr. 0·835.

Diagram No. 3.

With careful working, it is quite possible to keep this variation well below 2° C.

Three different crude oils were distilled in this apparatus, and the results compared with the distillation of the same crudes in a flask fitted with thermometers for taking the temperatures of the vapour and the residual oil.

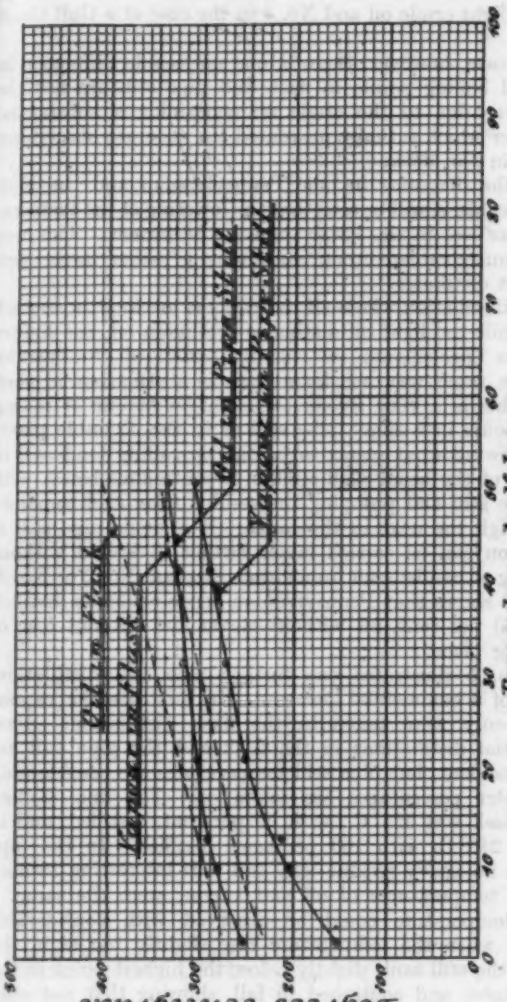
The curves shown on Diagram No. 2 give the comparison in the case of a Pennsylvanian crude oil.

It will be noticed that the initial distillation temperatures of oil and vapour were sensibly the same in both flask and pipe still, but, as temperatures rose and the proportion of distillate increased, the pipe still temperatures fell considerably below the temperatures for the same percentage distilled in the flask.

With 50 per cent. distilled, the oil temperature in the pipe still was 95° C. below and the vapour temperature 50° C. below the corresponding flask temperatures.

The distillation curves shown in the diagram enforce attention to one other salient difference between the flask and pipe still distillations. In the flask, the difference between the oil and vapour temperatures is seen to increase as the temperatures rise, whereas, in the pipe still, this difference decreases. This is, of course, due to the fact that vapour temperatures as taken in a flask distillation are not the temperatures of the vapour as it leaves the oil, but the temperature of the vapour after it has been cooled considerably in rising from the oil surface to the vapour outlet. This cooling is naturally greater as the temperature of the vapour rises and more heat is lost by radiation. It is very difficult to observe in flask distillation the real difference in temperature between the oil and vapour as it leaves the oil. Various arrangements of flask distillation have been proposed by Young and Brown, and other chemists, in order to observe this temperature difference more accurately, but the writer is of opinion that none of these arrangements approach the pipe still here described in accuracy.

From the point of view of the engineer, who has to design distillation plant with its necessary adjuncts of residue and vapour heat interchangers, it is important that the difference of temperature between oil and vapour should be known with fair accuracy. There is at present no known method of calculating this difference. It would probably be necessary to do some research work on the mean molecular weights of residue and distillate at various percentages distilled for each oil in order to obtain the necessary data for such calculation, but without such work the pipe still described would seem the only available method of getting the necessary information.



Distillation of Gulf Coast Crude. Sp. Gr. 0·923.

Diagram № 4.

Diagram No. 3 shows similar results in the case of an average Mid-Continent light crude oil and No. 4 in the case of a Gulf Coast crude.

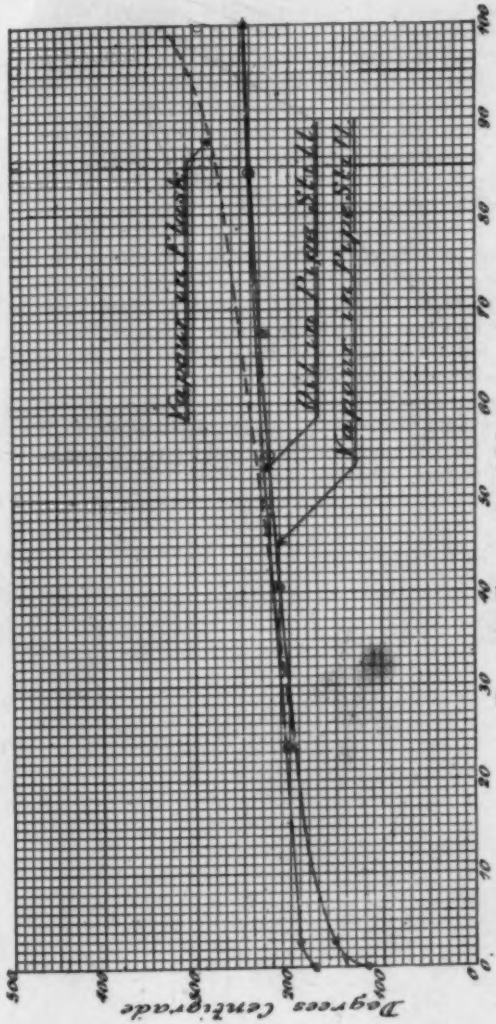
In this last case, however, there is one noticeable difference in that the initial boiling points in flask and pipe still are not the same. This was due to the crude oil containing a substantial amount of water which actually prevented the accurate observance of the I.B.P. in the flask.

Comparing the diagrams for the Pennsylvanian and the Mid-Continent crude oils, it will be seen that the lowering of the temperatures was rather less in the latter than in the former. This was due to the Pennsylvanian crude containing a rather larger percentage of light distillates.

In pipe still distillation where all the vapours are kept in contact with the oil while the light oil distillates are taken off, the lighter vapours act as "propellants" in the distillation of the heavier vapours in the same way as steam does in distillation in shell type stills. This is a very strong argument in favour of taking off all the vapours in a single pipe still as in the Trumble plant, instead of following what seems to be the prevailing tendency of replacing each of the usual shell stills of a continuous bench with a separate pipe still and pumping the residue from each separate pipe still through the next in the series. If a single pipe still is used, distillation can be carried much further if desired without fear of cracking as can be seen from either Diagram No. 2 or No. 3. Diagram No. 2 shows that Pennsylvanian crude could be distilled up to about 80 per cent. off without steam and without fear of cracking taking place.

Diagram No. 5 illustrates one further pipe still distillation, namely, that of a commercial kerosene. In this case the vapour temperatures only were taken in the flask distillation. Here, again, the initial distillations in the flask and the pipe still are seen to be coincident, but pipe still temperatures are considerably lower as greater percentages are taken off. The final boiling point in the flask was 325° C., with 99 per cent. distilled, and in the pipe still 245° C. with 100 per cent. distilled. In the pipe still there was no heavy residue left, and it is interesting to note that the final temperatures of oil and vapour were the same.

The final temperature could be observed with considerable exactitude as, when the temperature rose slightly too high, the level of oil in the still sank slightly below the highest point in the bent residue tube, and continued to fall, showing that not only was all the oil fed to the still evaporated, but the oil remaining from the previous portion of the distillation was being carried over also. If, on the other hand, the temperature fell a degree



Distillation of Commercial Kerosene.

Diagram № 5.

below the final boiling point, the level of the oil in the residue tube slowly rose again and a very small percentage of residue again dropped from the residue outlet.

The pipe still can thus be used for observing the equilibrium temperatures of light distillates, and these equilibrium temperatures have recently received a certain amount of attention in America, where it has been proposed to use the equilibrium temperatures of gasolines as a standard test of their quality. This example shows that it is possible to redistil a light oil distillate completely in a pipe still with 100 per cent. recovery, whereas it would be impossible in a shell type still.

The distillation of oils containing a fair percentage of water can be carried out comparatively easily in the still so long as the vapour temperature is above 100° C., so that water does not condense in the upper part of the separating chamber.

It may be of interest to note that the thermal efficiency of this apparatus, even when distilling up to a temperature of 300° C., is over 50 per cent.

The writer's thanks are due to the authorities at the Royal School of Mines for the permission to conduct the above experiments in the laboratory there.

Factors affecting Internal Combustion.*

By C. I. Kelly, M.Sc., A.I.C., F.C.S.
(Associate Member.)

Historical Introduction.

Robert Street built the first real gas engine in this country in 1794, and he obtained inflammable vapour from turpentine vaporised on the heated bottom of the engine cylinder, ignition being made from a flame through a touch-hole. It was left to Brown in 1823 to produce a successful hot-air engine, which can be considered to be the precursor of the modern internal combustion engine. In modern engines the external heating of the air in Brown's engine is dispensed with, the working fluid being the hot gaseous products of combustion of fuel vapour in air.

Whilst Lebon, in France, in 1799, described an engine operating on gas and air compressed before ignition, the compression system now largely used in gas engines was effectively worked by Barnett only in 1838. Lenoir, in 1860, was the first, however, to invent the gas engine used regularly by the public.

Up to that time most, if not all, of the engines were made to work on the flame-ignition system, but in 1855 A. V. Newton described and used the hot-surface ignition method, whilst Barsanti and Mattencci first used the electric spark method in 1857.

In 1862, Beau de Rochas patented his well-known cycle requiring four strokes of the piston for its completion. Otto followed closely in 1863, and in 1873, he and Langen produced their free-piston gas engine. The first practical petrol engine appears to have been made in Vienna by Julius Hock in 1870. America saw a decided advance in 1873 in Brayton's compression oil engine, though its economy was not good. Further interest centres keenly on Daimler's small high-speed engine, with its surface carburettor, using low-boiling petroleum, and which was brought out in 1883. His first motor cycle appeared in 1886 and in the following year he used the engine to propel a motor car. His experiences enabled Panhard and Levassor to make marketable motor cars for the first time in Paris in 1889.

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* Paper read before a joint meeting of the London Branch, Students' Section, of the Institution of Petroleum Technologists and the London Graduates of the Institution of Automobile Engineers at Watergate House, Adelphi, W.C. 2, on Thursday, December 16th, 1926, at 7.30 p.m.

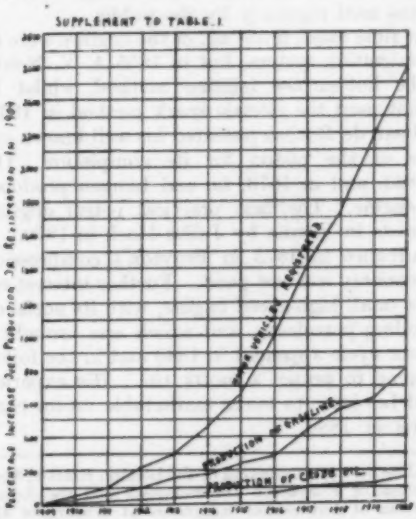
Heavy oil engines were studied by Diesel in 1862 and his efforts resulted in the first Diesel engine in 1895.

In England, the first internal-combustion engined car to run on the road was made by Knight in the early part of 1896, and this was followed by that of Lanchesters in July of the same year.

From then till now, cars have increased in utility, popularity, size, speed and efficiency and within the short period of 30 years, from the time when a motor car was looked on as a curiosity, one out of every eight persons in the U.S.A. owns a motor car. Table 1 shows the increase in the number of cars used in America together with figures for production over the same period :—

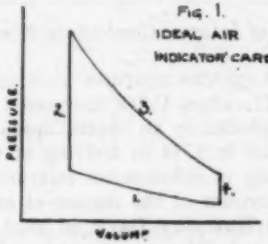
TABLE I.

Year.	No. of registered vehicles.	Production in 1000's of barrels of 42 U.S. gallons. Crude petroleum.	Gasoline.	Percentage gasoline to production of crude petroleum.
1895	4	52,892	—	—
1899	10,000	57,071	6,680	12·6
1909	312,008	183,171	12,900	7·1
1914	1,711,339	263,763	34,763	13·08
1920	9,231,941	442,929	116,251	26·25
1924	17,591,981	713,940	213,325	29·88
1975	54,060,000	—— predicted ——	547,156	—



The phenomenal rate of increase in the number of cars using petrol had a large effect on the petroleum industry. The amount of petrol available per car annually is steadily diminishing. The refiner has endeavoured to meet the demand and he has been assisted in recent years by having crude oils which yield more petrol than the older crudes. He is making more use of cracking processes, in this way converting high-boiling fractions into saleable gasoline, and has increased the boiling range of the spirit, thus making incursions into the kerosene fraction which was the chief product of the refinery in the early days of the industry. Whereas many years ago, petrol had a final boiling point of about 130° C., nowadays one finds petrols having f.b.p's as high as 200° C., and in America a f.b.p. of 230° C. is met frequently. The refiner, of course, would like to go further, but a practical limit is set by the design of internal combustion engines using the petrol, and by the danger of excessively diluting the crank-case lubricant with the "heavy fuel ends."

To illustrate the former point, one has to indicate that in constant volume engine practice, one has the ideal indicator diagram shown in Fig. 1. Curve 1 represents the adiabatic compression stroke;



2, the instantaneous rise of pressure at constant volume; 3, the adiabatic expansion stroke; and 4, the reversion of the working fluid to the original conditions of temperature and pressure. Thermodynamics leads to the following expression for the efficiency of the process.

$$E = 1 - \left(\frac{1}{R}\right)^{\delta - 1}$$

where R = the compression ratio
δ = the ratio of the specific heats of the working fluid.

Taking δ as a constant, it is seen that the efficiency of the engine increases with an increase of compression ratio. The designer

has this in view, but he is unable to make full use of it because of the limitations of the fuel. Too drastic an increase of the compression ratio, considering any one fuel, leads to two main troubles, *i.e.*, pre-ignition and detonation. On the other hand, an excessive increase in the F.B.P. of the petrol makes the occurrence of these two phenomena easier still. Neither of these is desired because they seriously interfere with the efficiency and power output existing immediately before their advent.

These two conflicting desires (that of the refiner to increase his yield of petrol by increasing its boiling range, and that of the engine designer to increase the efficiency of his engine) coupled with a common desire to make the most of the resources of natural fuel, have led to the intensive study of these two phenomena. But to get at the root of the matter, a clear knowledge of the process of combustion of inflammable mixtures generally, and particularly of combustion in enclosed spaces has to be sought. The present state of knowledge on the subject gives one a more or less clear idea of the most important factors influencing internal combustion.

A Study of Internal Combustion Processes.

The first time that gaseous mixtures were studied as explosive mixtures, was in 1777, when Volta discovered that hydrogen-air mixtures could be exploded by an electric spark. Cavendish made use of this information in 1784 in arriving at the composition of water. Intensive study of inflammable mixtures, found necessary soon afterwards on account of the danger of explosions in mines, was initiated by Sir Humphry Davy, in 1816. Actual measurements of explosion velocities were not made, however, until Bunsen developed new methods and technique in 1867. Then followed the discovery of the Detonation Wave by Berthelot and Le Chatelier independently in 1881, whose methods of measurement of the velocities of, and the pressures set up by, the explosion wave (detonation wave) paved the way for the work of Dixon and other modern workers. Since then, the study of the combustion of gaseous mixtures in closed vessels has advanced rapidly.

The work viewed collectively, whilst being insufficient to explain many vexed questions, has led to a very wide knowledge of the factors influencing gaseous combustion and of their relation, one to another. This is shown by the very interesting chart (Table 2) recently put forward by Dr. W. E. Garner.

Whilst the above scheme* is not claimed to be complete, it serves to show, at least, the inter-relation of the main factors and also the complexity of the subject of study.

The way in which some of these factors enter into processes of combustion can be illustrated by considering a few cases of tube experiments.

The simplest method of burning a gaseous mixture is at the end of a tube as in the case of the Bunsen burner. Here the burning gases are free to expand and no increase of pressure is caused by the expansion of the hot products of combustion. The flame velocity depends upon the nature and proportions of the constituent gases. The temperature of the products of combustion will vary with the heat of reaction—and so on. The familiar striking back of a Bunsen burner is simply due to the fact that the velocity of the flame through the gases is greater than the

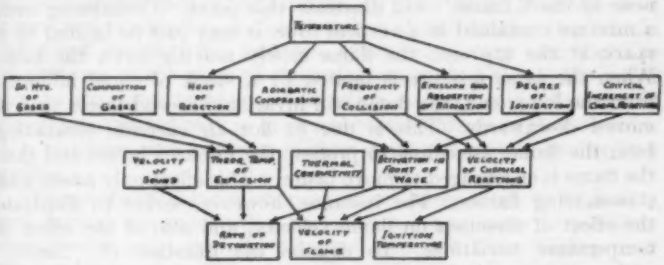


TABLE 2.

velocity of the gases at the mouth of the burner. Should these two velocities be equal, the flame will hover about, or slightly inside, the top of the tube. A slight reduction in gas velocity will then allow the flame to "strike back." The velocity of the gases at the mouth of the tube under such conditions will, therefore, give a fair value for the flame velocity. Bunsen utilised this method for flame velocity determinations.

But when the gases are burnt in confined spaces, the flame velocity is considerably altered, due chiefly to the expansion of the burnt gases and the compression of the unburnt portion.

One has not to forget, however, the well-established fact that before a mixture of gases can be ignited, the proportions of both have to lie within what are called "the limits of inflammability."

* W. E. Garner, *Faraday Soc.*, April, 1926.

These vary with different gases, the nature of source of ignition, size of vessel and the direction of flame travel.

TABLE 3.

Limits of Inflammability.

Combustible.	Lower.	Higher.	
Petrols	1·5 ..	6·0 % vapour	Air being the supporter of combustion.
Benzene	1·4 ..	7·5 % "	
Ethyl alcohol ..	3·56 ..	18·0 % "	
Methyl alcohol ..	7·05 ..	36·5 % "	
Hydrogen	7·0 ..	72·0 % gas	
Carbon monoxide ..	16·0 ..	72·0 % "	

The tube diameter affects the limits because the smaller the diameter, the greater the heat loss to the walls. Then again, there are variations due to the direction of flame travel. The velocity of slow-moving flames, *i.e.*, in gases, the proportions of which are near to the "limits," will illustrate this point. Considering such a mixture contained in a vertical tube, it may just be ignited by a spark at the top end, the flame slowly moving down the tube. When the same mixture is ignited by a spark of equal intensity from the lower end, the flame will invariably ascend faster than it moved downwards. This is due to hot air currents emanating from the flame, ascending to preheat the unburnt layers and thus the flame is encouraged to move faster. This effect only arises with slow-moving flames. The instance, however, serves to illustrate the effect of direction on flame velocity, and also of the effect of temperature variations. To dismiss the question of "limits" without too much detail, one can only add that an increase of temperature and/or pressure widen them, whilst turbulence brings them closer.

Assuming now that the mixture is of such a composition that flame can be self-propagated through its whole mass, it is interesting to follow the process of initiation of flame and its subsequent growth and spread through the mixture. Considering a stagnant charge, the increase of temperature in the locality of the source of ignition has to be such that the temperature of a definite amount of gas in that neighbourhood is raised at least to its ignition temperature. (This implies that the igniting spark has to possess a definite amount of energy to start combustion). That mass of gas becomes inflamed, but before the flame can proceed, the heat liberated during the combustion of that small amount of gas (controlled by the heat of reaction), has to be sufficient to raise the next layer of unburnt mixture up to its ignition temperature. The ease with which this can be done depends on many factors, the chief of which are the Ignition Temperature, the Thermal Conductivity (*i.e.*, the ability

to conduct heat) and also on their Specific Heats, the higher these are the more likely is the flame to be "quenched." A similar consideration underlies the principle of the Davy Safety Lamp, in which the metallic gauze inside the lamp, rapidly abstracts the heat from the flame—which may be propagated inside the lamp towards it—thus preventing the layer of inflammable gas outside the gauze from being elevated to its ignition point.

At this stage of its formation the flame, being of slow velocity, can be influenced by such a variable as radiation. It is well-known that hot masses radiate heat waves, the frequency of which vary with the temperature of the radiating mass. This equally applies to flames and the emitted radiation must have some effect large or small. But before it can have any real effect on the unburnt gases immediately in front of the flame, the gases have to be able to absorb them. However, assuming that the radiation could be absorbed, the unburnt gases would acquire an increased energy content, an increase in temperature, and this would have the effect mentioned above, *i.e.*, an acceleration of the flame. One should point out also that this radiation effect would vary with the time of exposure of the gases to the radiation, so that this factor would not be expected to have much effect on very rapid flames. It would be expected only to have pronounced effects on slow combustion processes such as occur in slow speed gas engines having long strokes.

The nature of flame movement immediately after its formation will depend on many other variables too numerous to mention. Perhaps the most usefully discussed here are those arising from the conditions of confinement. For instance, if ignition has been made from the closed end of a tube open at the other to the atmosphere, the flame not only travels forward by virtue of its velocity through the gas, but also on account of the expansion of the products of combustion contained in the closed end. Then again the effect of this acceleration varies with the length of the tube. In a short one the bulk of the gases will be "pushed" out, and will burn at the mouth of the tube. But if the tube is very long, the flame velocity increases until it attains an extremely high value, characteristic of an explosion, in many of which cases the tube is shattered to pieces.

Ignition from the open end of a tube closed at the other, gives rise to an entirely different set of results. In this case, the flame quickly accelerates over a very short distance, and then proceeds at a uniform velocity for a length of time governed by several other factors. This period of uniform movement is then followed by a series of vibratory movements, the flame first of all stopping, then perhaps turning back, then moving forward, all the time tending

to approach the closed end. If the tube is small, there is no other change, but in a long tube this vibratory movement suddenly gives way to a very rapid increase in the flame velocity, which again appears to be characteristic of an explosion. Table 4 gives some idea of the great differences between flame velocity during the period of uniform movement and when the explosion is set up, and of the effect of increased mixture strength on these velocities.

TABLE 4.

Percentage hydrogen in oxygen.	Speed in metres per sec. Flame.	Explosion.
59·9 ..	5·74 ..	2650
66·6 ..	6·62 ..	2824
75·2 ..	5·15 ..	3140

Still further changes in the nature of flame movement are experienced when combustion is carried out in a completely closed vessel. In these conditions of confinement, acceleration of flame is very much magnified, the effects of the expansion of the burnt portion and the compression of the unburnt, making themselves more evident. Tube length and the velocity of the flame in the initial stages both play prominent parts. The more rapid flames prevent that equalisation of pressure throughout the burnt and unburnt portions which is characteristic of slow burning mixtures. The compression of the unburnt portion in the case of very rapidly burning mixtures becomes more alike to adiabatic compression, the faster the flame movement. Such conditions soon tend to produce the self-ignition of the unburnt portion, the resulting reaction not being of the nature of true combustion, during which there is a regular and organised rate of increase of pressure. This inability to equalise pressure frequently sets up what is called a compression or detonation wave which travels forward at an incredibly high speed through the unburnt and burnt gases. In its passage through the unburnt portion it stimulates the interaction of the gases.

So far, the combustion process, as it is affected by the variables occurring in tube experiments, has been treated in a general sense and gives one a small idea of the complexity of the process. One has only discussed experiments in which stagnant gases were used. Neither has any mention been made of the effects which arise from the method of ignition adopted in engines working on petrol vapours and air. Although spark ignition is general in these engines, one very often loses sight of the fact that such a method of ignition can profoundly influence the combustion process which it initiates, and that these effects do not arise when gases are ignited by flames or hot surfaces.

A spark which initiates combustion also gives rise to a spark or compression wave which has the velocity of sound, and which has a similar effect as the compression wave mentioned earlier on. It has the effect of hurrying up the flame if it approaches it from behind and of arresting it should it approach the flame front from the opposite direction. Its path through the gases is easily traced in photographs of the combustion, because of the increased luminosity which arises from the intensified combustion promoted by its passage through the gas. Its effect in the first place is to confer on the gas molecules a velocity in the direction in which the wave is moving. Consequently, as the wave hits the boundary of the vessel and is reflected to and fro, the flame has to traverse a gas, the molecules of which are varying their direction. Should this wave overtake a flame which is already moving forward very rapidly, the resultant effect may be the production of a detonation wave.

The subject is dealt with in Fig. 2.* The experiment was ignition of a gas in a tube closed at both ends, by means of a spark from the middle of the tube. It will be seen that the wave arising from the spark reaches the right hand end before the flame and is then reflected back. The reflected wave meets the advancing flame when the latter is about one-eighth of the length of the tube from the end. The result is that the velocity of the flame relative to the tube, becomes zero for a short time and then it is suddenly increased by the impetus received from the wave, which has been reflected from the other end and which has caught it up. Perhaps of more interest to automobile engineers is Fig. 3.† Here Dixon photographed what was going on in a tube, the gases in which were being compressed when a spark was formed near one end. The stimulating effect of the waves referred to above can be more appreciated by comparing this slide with Fig. 4.† This is taken without the spark, the final compression temperature being sufficient to ignite the gases spontaneously. There are no signs of waves, such as are shown by Figs. 2 and 3. The freedom from waves is also the case where gases are ignited by small flames. When Mason and Wheeler‡ were studying the "period of uniform movement," they compared photographs of flames produced by sparks and flames. Where spark ignition had been used, the influence of waves was evident, but it was absent when a flame was the source of ignition. Another interesting feature of these photographs is the pronounced undulation in the movement of the flames produced by sparks. The pulse or boosting effect

* H. B. Dixon, *Phil. Trans.*, A. **200**, 1903, 326.
† Dixon, Bradshaw, Campbell, *J.C.S.*, 1914, **105**, 2027.
‡ *J.C.S.*, 1919, **115**, 81.

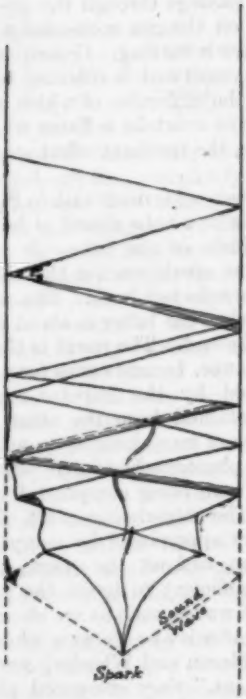


FIG. 2.

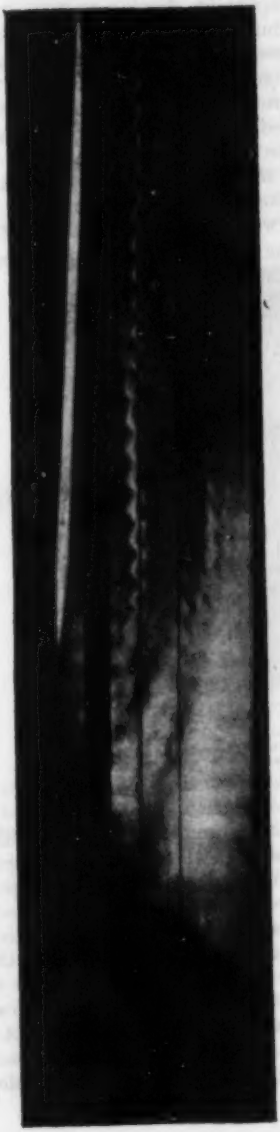
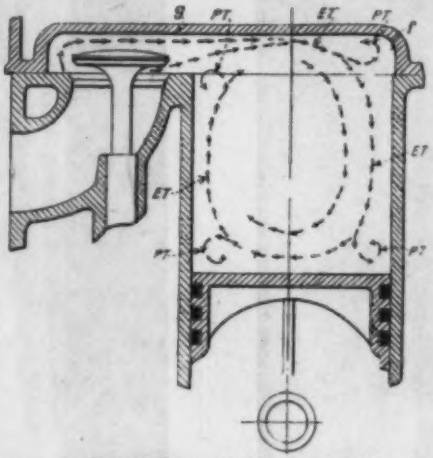


FIG. 3.

FIG. 4.

of the spark must have been responsible for some part of the undulatory movement. The undulations must also have been due in part to the resonance induced in the tube by the pulsation produced when the suddenly ignited gases expanded. This contention is supported by measurements of the frequency of the tube in which the gases were ignited. The undulatory movement, however, does not affect the linear velocity of the flame.

The foregoing makes it evident that the process of combustion in tubes has been studied very extensively and that most of the factors affecting the process are well understood. Their effects are equally known, conclusions being made possible by the accurate



—An Ordinary Type of L-Head Combustion-Chamber Showing Two Possible Locations for the Spark-Plug

Fig. 5.

photographic methods used for measurement purposes. The perfection of these methods has enabled a clear understanding of detonation as it occurs in tubes. Views on this subject as permitted by the above and similar experiments are briefly these. It is agreed that the explosion takes place with great rapidity, emitting a loud noise, and that it is often accompanied by the shattering of the containing vessel (glass). The combustion in such cases takes the form of a detonation wave. This wave is so definite that Dixon has been able to measure its velocity photographically. All experiments go to show that Berthelot was not far wrong in his belief that the velocity of the wave corresponded

to the average velocity of the molecules at the maximum flame temperature.

Conditions in a closed tube containing a stagnant mixture differ very markedly from these occurring in an engine cylinder, which contains a turbulent mixture and one boundary of which is moving during the initiation and spread of the flame. Whilst the two cases differ in many respects, various factors are common to both. Outstanding of these is the part played by combustion chamber design. To consider one case only (dealt with more fully in a paper by Ricardo),* Fig. 5 shows a combustion chamber of parti-

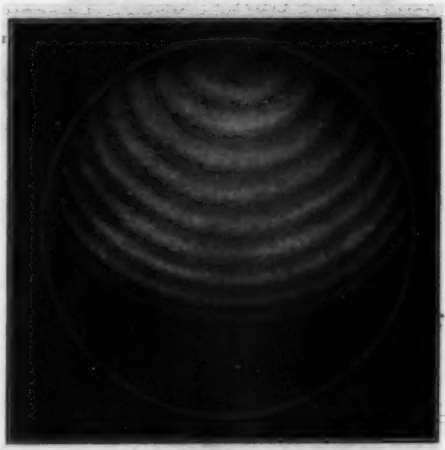


FIG. 6A.

Exposures of 0·00169 sec. at intervals of 0·00458 sec.

cular design. With the spark plug at F there is a very long distance to be travelled by the flame to the end of the pocket above the valve to the left. When the flame reaches this point there would exist in the cylinder the pressure developed by the combustion of the major portion of the mixture. Such conditions would be expected to make detonation a very real possibility because it was seen in the case of the experiments with ignition of gases at the closed end of a tube open at the other, that the longer the run the flame could get, the more likely was detonation to set in. Placing the spark plug at G materially lessens this tendency. In petrol engine practice, it is generally considered that central

* H. R. Ricardo, *J. Soc. Auto. Eng.*, 1922, 10, 334.

ignition is best, the flame having almost equal distances to travel to all the boundaries. If, on the other hand, central ignition is not possible, two plugs placed symmetrically are better than one not central.

In this connection, it is interesting to turn to some observations made by Ellis and Wheeler and to some of the photographs they obtained with an ingenious apparatus. Fig. 6A* shows the movement of flame from a spark formed at the highest point of the periphery of a spherical vessel. It can be seen in this and in

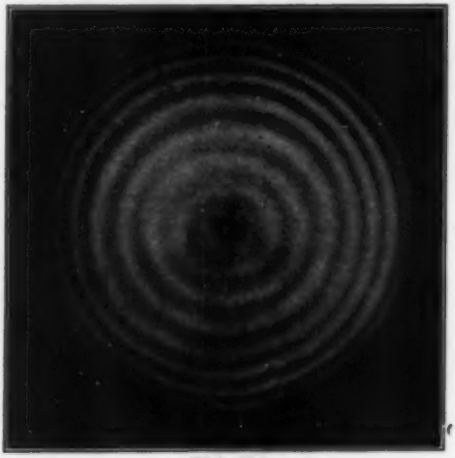


FIG. 6B.

Fig. 6B,* in which ignition is at the centre, that the flame endeavours to touch all the bounding surfaces at the same instant, and succeeds in the latter case. Figs. 6 (*c* and *d*),† shows the progress of flame in a vessel cylindrical in shape (diameter equals length), and how pockets are formed in the corners. The flame will be seen to be trying to squeeze into the corners whilst it touches the four boundaries in the middle. The position of the source of ignition has a more striking effect in that it affects the rate of rise of pressure and the maximum pressure developed by the combustion in each case of the same volume of mixture under similar initial conditions. These points are clearly set out in Fig. 7.‡

* *Fuel*, 1925, No. 8, 356.
† Ellis and Wheeler, *J.C.S.*, 1925, **127**, 764.
‡ Ellis and Wheeler, *Fuel*, *ibid.*

All these data were got using stagnant gases. One has to turn to a photograph by Wheeler* to appreciate what goes on when a turbulent mixture is ignited in a spherical vessel. The flame

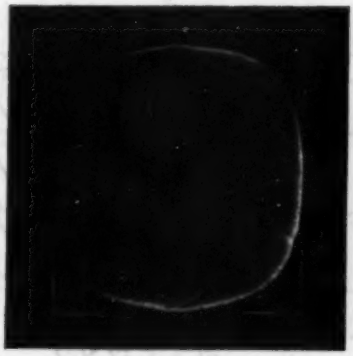


FIG. 6c.
After 0·03644 sec.

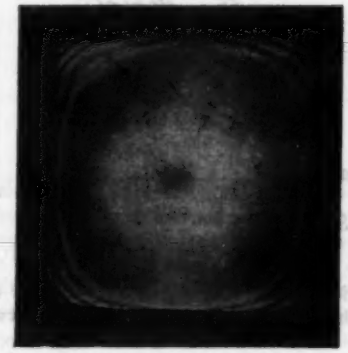


FIG. 6D.
After 0·03644 sec. and at subsequent intervals.

has the appearance of a rolled-up ball of paper. These experiments also showed that it is more difficult to start combustion in turbulent gases present in the proportions of the "lower limit" for stagnant conditions, and that a richer mixture had to be used. When

* Wheeler, *J.C.S.*, 1919, **115**, 81.

the flame could self-propagate itself, it sped through the gases very much more rapidly under the turbulent conditions than it did in a similar mixture in a stagnant state. Consequently the rate of propagation of flame was greater as is shown in Fig. 8.* It

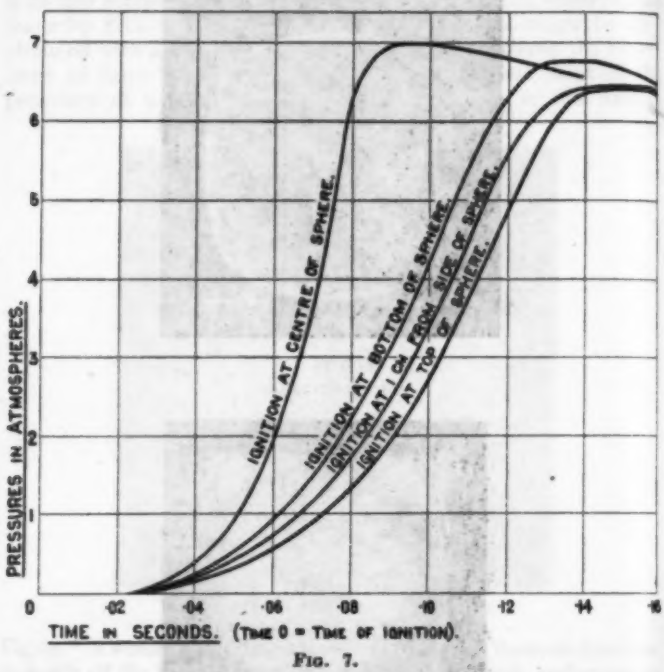


FIG. 7.

was further evident that the flame first spread towards the axis of rotation of the gases and then it was swept outwards. It seems, therefore, that even in conditions of turbulence, one can expect the flame to get to the portions of the gas most distant from the axis of rotation after the bulk of the mixture has burnt.

It must, however, be realised that turbulence always tends to minimise the existence of out-of-the-way pockets of gas, as will be realised by referring to Fig. 5, which shows by means of arrowed lines the probable path that the intake gases would pursue in such a chamber. Further, turbulence does not entirely remove the

* Wheeler, *J.C.S.*, 1919, **115**, 81.

occurrence of detonation, although it materially lessens the probability of its taking place. The degree of turbulence of course depends on the position of the inlet valves, inlet gas velocity, and the general shape of the combustion chamber. This stresses the important relation between chamber design and the occurrence of detonation. Table 5* gives a brief summary of Ricardo's

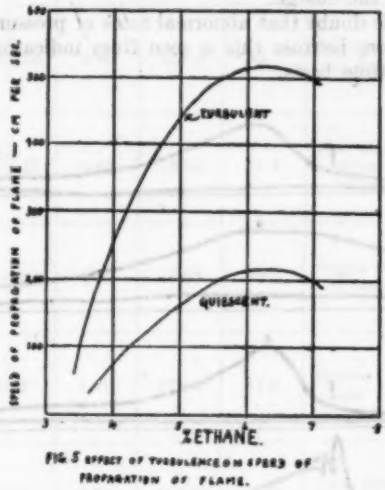


FIG. 5 EFFECT OF TURBULENCE ON SPEED OF PROPAGATION OF FLAME.

FIG. 8.

observations on the utility of various types of cylinder head and the position of the spark plugs from the viewpoint of detonation.

It has been mentioned that detonation in an engine may be quite different to detonation in tube experiments although there are several features common to both. Its occurrence has been described for tubes and at this point it would be serving a useful purpose to discuss it more from the engine standpoint, particularly on account of the fact that those factors which influence detonation are the most important in the eyes of the automobile engineer.

This part of the study has been rendered somewhat difficult because of the confusion that exists between detonation and pre-ignition, both of which are similar in some respects but quite different on major points. Pre-ignition makes itself evident by emitting a dull thud from the engine, and by causing an immediate drop in power output. When detonation occurs—or rather,

* Ricardo, *J. Soc. Auto. Eng.*, 1922, **10**, 305.

detonation is considered to occur when—a sharp metallic sound arises from the cylinders. It is, however, unlike pre-ignition in that it frequently gives rise to a slight increase in power output. This does not continue for long because the excessive temperatures and pressures produced by it tend to give rise to over-heated spots in the combustion chamber, and these in turn may give rise to pre-ignition of the charge.

There is little doubt that abnormal rates of pressure rise accompany detonation, because this is seen from indicator cards taken on a pressure-time basis.

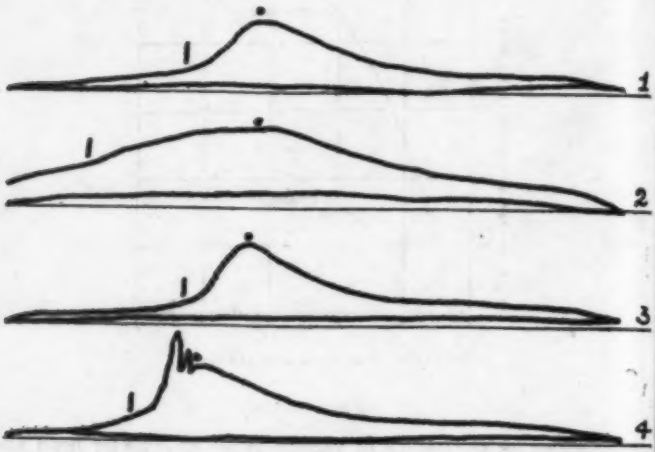


FIG. 9.

The four indicator cards (Fig. 9*) show the pressure rise against a time basis for :—

(1) Alcohol. Note smooth combustion curve before top dead centre (shown by small dot).

(2) Carbon Disulphide. Note pressure rise due to pre-ignition, *i.e.*, to ignition before spark passes (shown by small vertical stroke).

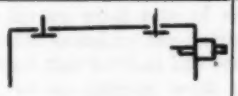
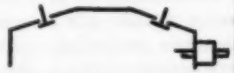
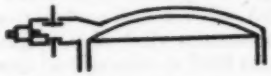
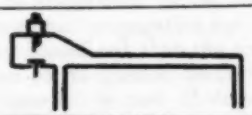
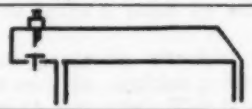
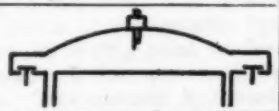
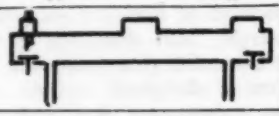
(3) Petrol, High F.B.P. poor volatility. Note more rapid pressure rise before T.D.C. as compared with alcohol.

(4) Kerosene-Ether Mixture. Note abnormal pressure rise due to detonation setting in before T.D.C.

* Kettering, *J. Soc. Auto. Eng.*, 1919, **5**, 198.

TABLE 5.

Results of Tests on various Types of Engines.

Type.	Type of cylind. head.	Form of head and position of spark plugs.	No. of valves.	Vol. of cylind. cu. ins.	Compr. ratio.	I.M.E.P. lbs/ sq. in.	Mech. efficiency %.	Remarks on performance.
Automobile	Plain cyl-ical		2	30·80	4·80	137·5	83	Slight tendency to detonate.
Racing motorcycle	Pent roof		4	30·40	5·40	139·0	87·5	No detonation under any circumstances.
Aeronautic	Pent roof		4	72·60	4·80	136·5	88·0	Slight tendency to detonate.
Motor truck	T-head		2	101·2	4·70	123·0	83·9	Severe detonation.
Motor truck	Special side valve		2	99·2	4·70	118·0	88·0	Very little detonation.
Automobile	Ord. type side valve		2	99·2	3·40	100·0	86·0	Severe detonation.
Motor truck	T-head		2	94·6	4·25	104·0	90·5	No detonation.
Motor truck	T-head		2	95·2	4·00	94	81·0	Severe detonation.

Ricardo. *J. Soc. Auto. Eng.* 1922. **10**. 305.

Indicator cards of this type are, however, uncertain sources of information in circumstances of detonation, because one does not exactly know what rate of rise of pressure precedes detonation. Different types of indicators will give widely varying "cards" for the same conditions. On the other hand, it is generally preferred to follow the occurrence of detonation by the nature of the sounds emitted from the engine cylinder. This method is also open to criticism in that no one really knows what rate of rise of pressure is required to produce a metallic sound in the engine. There is no disputing the fact, however, that this method has been put to extremely good use by Ricardo, whose pioneer work on this point has clarified the air considerably.

Further, it has enabled Ricardo to put forward a very practical theory of detonation, which states: "An explosion wave occurs when the rapidity of combustion of that portion of the working fluid first ignited, is such that by its expansion it compresses before it the unburnt portion. When the rate of temperature rise due to compression by the burning portion of the charge, exceeds the rate at which it can get rid of its heat by conduction, convection and the like by a certain margin, the remaining portion ignites simultaneously throughout its whole bulk. This sets up an explosion wave which strikes the walls of the cylinder a hammer-like blow."

This view of detonation in an engine is usefully contrasted with the view put forward by Mallard and Le Chatelier in 1883 regarding the different way in which heat is transferred to the unburnt gases in front of the flame during its normal propagation and during detonation. In the first case, they considered that the unburnt layer of gas is heated by the flame to its ignition point by the process of thermal conduction, whereas in the case of detonation the unburnt layer is heated to its ignition point by adiabatic compression.

Both these views obviously call particular attention to the close relation that must exist between the ignition point of an inflammable gas and its tendency to detonate. This is correct as a general rule. The ignition points of the paraffin hydrocarbons decrease, with an increase of boiling point (molecular weight). The higher boiling paraffin H.C.'s are most easily detonated of all the hydrocarbons. The aromatic hydrocarbons have higher ignition points and are very resistant to detonation. This is not, however, a universally applicable rule. Hydrogen has a very high ignition point but it is more easily detonated than even the aromatic hydrocarbons. Carbon disulphide is exceptionally easy to pre-ignite at very low compression ratios (3·75 to 1) and yet it makes more resistant to detonation a paraffin hydrocarbon fuel of higher ignition point.

It is clear, therefore, that other factors enter into the question. Tizard* is clear on this point and he indicates that one of them must be the "temperature coefficient of the reaction" between the fuel vapour and the air. This view is reasonable, in the eyes of chemists who have experienced time and time again that certain reactions are accelerated more than others by the same rise of temperature. In the light of this, if one ascribes to the reaction between hydrogen and air a very much greater temperature coefficient than the reaction between benzene and air, one can see why hydrogen is more likely to detonate than benzene.

A third point also appears to affect detonation, one which is easy to understand, *i.e.*, the maximum temperature which is produced on combustion. This is controlled amongst other things by the flame temperature. This point is more easy to grasp, perhaps, because it is obvious that the higher the temperature to which a gas is elevated, the greater is the translational velocity of the molecules. This means to say that the number of impacts between the reacting molecules per unit of time is increased. One cannot, however, say that all impacts between reacting molecules are chemically fruitful. But it appears reasonable to suppose that an increase in the number of impacts per unit of time will lead to a larger number of molecules entering into the combustion process in that period of time. Hence one would expect an increased rate of rise of pressure, the more elevated the temperature. High temperatures are most likely to exist with high flame temperatures and more particularly the further combustion has proceeded.

Accepting these three factors as those which govern the occurrence of detonation one can explain several anomalies which would exist if one accepted ignition temperatures as the one and only factor. To take one particular case. Ricardo found, when working with his machine for measuring ignition temperatures by compression, that the ignition temperature varies only slightly with increased mixture strength. And yet, the richer the mixture, the more easily does it detonate. The variation of ignition temperature is too small to account for this. But it appears that the flame temperature varies very considerably with variations of mixture strength. Taking this into account and also that the temperature coefficient would be affected also, it is easy to see why detonation is likely to occur more readily with over rich mixtures. In fact, anything that affects the flame temperature, such as inert gases, water vapour, all influence the detonating tendency of a given fuel.

These three main variables are in turn related to the nature of the chemical composition of the combustible gas. This relation

* Tizard, *N.E. Coast Inst. Eng. and Shipbuilders*, 1921, **37**, 381.

has been emphasised by the work of Ricardo with his variable compression engine, which allows the compression ratio to be altered at will during the actual running of the engine. Detonation is detected orally and the intensity is considered to be proportional to the intensity of the sound arising from the cylinder. In passing one might draw attention to the method used by Midgley in America for similar work. In this engine, the compression ratio was varied by means of detachable heads fixed on the piston, so that the engine had to be stopped to alter the ratio. But instead of detecting detonation by sound, he fixed a pressure element in the cylinder head. The bouncing pin only closed the electrical circuit when abnormal rises of pressure caused it to move a large amount against the spring. When the circuit was closed, electrolysis of the acidulated water in the cell set in, with the liberation of gas, which was collected in the measuring tube. The intensity of the detonation was measured by the amount of gas liberated during a one-minute run. In most of the experiments on this engine, Midgley confirmed the conclusions of Ricardo that one could place the various hydrocarbons existing in a fuel in this order of resistance to detonation. Best of all were the alcohols, then came the aromatics, naphthenes, unsaturateds, and finally the paraffins.

Since then more work has been done, to bring out the marked effect on detonation of several other compounds which were only required to be present in very small quantities in order to have very marked effects. Table 6* lists some of these and also shows the amount of each which has the same effect as 25 per cent. of benzene in suppressing the detonation of a standard kerosene.

TABLE 6.

RELATIVE EFFECTS OF SOME COMPOUNDS FOR SUPPRESSION OF DETONATION COMPARED WITH BENZENE.

Element.	Compound.	% by vol. in kerosene giving same suppression of detonation.	Corresp. no. of gr. mols. of compd. in given vol. of fuel (kerosene).	No. of mols. of theor. fuel/air mixt. per 1 mol. of anti-detonating compd.
—	Benzene	25·00	1·0	150†
Iodine	C_2H_5I	1·60	0·07	2,150
Nitrogen	Xylidine	2·00	0·059	2,600
Tin	$(C_2H_5)_4Sn$	1·20	0·021	7,100
Selenium	$(C_2H_5)_2Se$	0·40	0·013	11,750
Tellurium	$(C_2H_5)_2Te$	0·10	0·003	50,000
Lead	$(C_2H_5)_4Pb$	0·04	0·0007	215,000

* Midgley and Boyd, *J. Ind. Eng. Chem.*, 1922, **14**, 894.

† The figures in this column are based on the assumption that the average molecule of the kerosene is $C_{12}H_{22}$.

Figures for the metallic compounds are available in a published report of work carried out at the Air Ministry Laboratory:—

TABLE 7.*

Compound added.	Wt. of metal/litre of petrol.	Wt. of compd./litre of petrol.	H.U.C. value.	Percentage increase in H.U.C. value.
	gr.	gr.		
Petrol + lead tetraethyl ..	2·0	3·2	6·45	40
„ + nickel tetracarbonyl	2·0	5·8	6·8	48
„ + iron pentacarbonyl	2·0	7·2	7·41	61
„ (straight)	0·0	0·0	4·6	0

This table shows that iron is superior to nickel or lead, if one compares them on the basis of weight of metal per unit volume of petrol. There is an inversion of the order if one compares the metals on the atomic basis. Since the increase in H.U.C.R. produced by these compounds is a straight line function of the weight of metal per unit volume of petrol, in the region of the concentrations stated above, one finds from the figures that in producing a 40 per cent. increase in H.U.C.R. of a petrol with each of the compounds, 1 atom of lead is equal in its effect to 2·37 atoms of iron and to 3 atoms of nickel.

In connection with the use of organo-metallic compounds as anti-knocks, it is interesting to note that such compounds may be expected to exert an anti-knock effect if (*a*) the metal is liberated on heating the compound; (*b*) that the metal is oxidisable; (*c*) and that the oxide is stable at the working temperatures. The anti-knock effect of the organic nitrogen compounds are of especial interest to chemists, as a definite relationship exists between the chemical constitution of the compounds and their effectiveness as suppressors of detonation. For instance, Boyd showed in 1924 that, as a general rule, the secondary amines are more effective than either the primary or tertiary amines. If radiation plays any part in the detonation-suppressing action of the amines, there is a possible explanation of the observations of Boyd by the Selective Radiation Theory. E. O. Saliant has recently been studying the infra red absorption of the amines, and he has found that dialkylamines and diphenylamine show absorption in the region 2·9 to 3·1 μ, whilst the tertiary amines do not. It further appears that this absorption is due to the $=$—NH linkage. This information is significant when one notes that a large fraction of the radiation emitted during combustion processes in petrol engines lies in this portion of the infra red spectrum.

* Sims and Mardles, *Faraday Soc.*, May, 1926.

It is impossible to treat this branch of the subject in more detail, chiefly because it is still wrapped up in controversy. It serves to show at least that much good work can be done by close co-operation between automobile engineer and chemist.

The author's thanks are due to Professor H. B. Dixon, F.R.S., for generously supplying slides of Fig. 2 for the purposes of the lecture, to various authors for permission to reproduce their illustrations and to the Institute of Automobile Engineers, Chemical Society, The Royal Society, and the Editors of "Fuel in Science and Practice" for the loan of blocks.

Historical Records Relating to Oil.*

By A. B. Cook, M.I.Mech.E., and Clare Despard.

In ancient History there are many allusions to Mineral Oils of an Asphaltic Origin, referred to under allusions to Ἄσφαλτος Νάφθα, Bitumen liquidum, etc. The Dead Sea was known as Ἀσφαλτῖτις λίμνη. The dates given below are approximate.

If we pass over the suggested references to the "slime" (see under Pliny below) used as mortar in building the Tower of Babel, and the yet older one to the "pitch" used by Noah in rendering the Ark watertight, the oldest reference that we have found appears to be :—

B.C. 484–425.—Herodotus (IV., 195) says: "I myself saw 'pitch' drawn from the water of a pool in Zacynthus (modern Zante, an island off the west coast of Greece). The pools there are many; the greatest of these is seventy feet long and broad and two fathoms deep; into this they drop a pole with a myrtle branch made fast to its end, and bring up pitch on the myrtle, smelling like asphalt, and for the rest better than the pitch of Persia. They then pour it into a pit that they have dug near the pool, and when much is collected there they fill their vessels from the pit."

B.C. 330.—According to Strabo (page 743) and Plutarch in his life of Alexander the Great (chap. 36), Alexander, during his expedition through Southern Asia, entered a certain city in Persia, when a demonstration was made by sprinkling an entire street with a bituminous oil (*νάφθα*) which was set on fire by torches and blazed fiercely.

On another occasion Alexander the Great was taking a bath, with attendants standing by with bowls of water, when it was suggested that it would be an interesting experiment to smear a youth named Stephanos, who was standing by, with this oil. Alexander was pleased, and the youth, who consented, was then drenched with the oil, and a lighted torch applied, when he took fire, and had not the attendants promptly flung their bowls of water over the youth, the experiment might have proved fatal, even as it was he was in a pitiable condition (*χαλεπῶς ἔσχεν*).

B.C. 124.—In the Apochrypha (II. Maccabees, which was derived from a larger work by an African Hellenist, named Jason, of

* Paper received February 2nd, 1927.

Cyrene) in Chap. I. there is an interesting account of the cleansing of the Temple at Jerusalem after it had been profaned by Antiochus Epiphanes, by Neemas, an envoy of the King of Persia, which relates how "they found . . . thick water . . . and when the sacrifices were laid on, Neemas bade them draw it up, and commanded the Priests to sprinkle the wood and the things thereon with the water. When this was done, and the time came that the sun shone (which afore was hid in the cloud), there was a great fire kindled, so that every man marvelled (v. 35), and Neemas called this thing *νάφθα*, which is as much as to say 'a cleansing,' but many men called it *νέφι*." A modern commentator writes that these words (naphtha and nephi) may perhaps be connected

with naphtha, a pure water-like oil (petroleum) found in mineral wells in Persia.

It would appear to be suggested, but not definitely stated, that the sacrificial fire, referred to in chap. i., v. 22, was kindled by the direct action of the sun's rays. In chap. x., v. 3, however, which possibly alludes to the same event, it is stated definitely that by "striking stones they took fire out of them and offered a sacrifice. . . ."

B.C. 100.—A silver coin (value one denarius) was struck at Apollonia, in Illyricum (S.E. Adriatic), on the obverse of which appear the figures of three nymphs, one of whom is holding a flaming torch. These nymphs are dancing round a bowl, through which are issuing flames from a spring of blazing petroleum. This

and similar coins can be seen in the British Museum and at Cambridge University.

B.C. 63 ; *A.D.* 24.—Strabo also alludes to this flaming well, and mentions that hot springs were to be found in the neighbourhood, as well as a mine or quarry from which bitumen was dug.

B.C. 30.—Virgil in his Georgics, Book III., line 451, speaks of asphaltic oil being used externally on sheep after shearing as a preventative or remedy against scabies : "A foul murrain assails the sheep . . . when the sweat not washed away adheres to them after shearing, and . . . on this account the shepherds wash all the flock in fresh rivers, and the ram with humid fleece is plunged into the pool, and sent to float along the stream ; or they beamear their bodies after shearing with bitter lees of oil, and mix litharge, native sulphur, Idæan pitch, and fat unctuous wax, and sea-leek, rank hellebore, and black bitumen."

A.D. 46–125.—Plutarch, in his life of Sulla (chap. 27), refers to the flaming well at Apollonia, adding that though it burned with a brisk flame, green vegetation grew naturally within quite a short distance.

A.D. 70.—Pliny, writing about A.D. 70, in his book on Natural History, Book XXXV., chap. 51., describes several varieties of bitumen, and mentions twenty-seven remedies into the composition of which it enters. He says that bitumen is in nature akin to sulphur, and that it is found in solid, slimy and liquid conditions. From Sidon it is obtained in solid form. As a slime from a certain lake in Judea, from Zacynthus and from Babylon it was obtained in a liquid condition. The Babylonish grade being "water white," all three varieties being included in the generic name of πεσσασφάλτος as bearing a strong resemblance to a compound of pitch and bitumen.

An oily liquid bitumen was also obtained from a spring at Agregentum in Sicily. The inhabitants of that district collect it on the panicles of reeds, to which it readily adheres. They used it in lamps as a substitute for oil, and as a cure for scabies in beasts of burden.

Some authorities, he adds, include naphtha among the bitumens (see Pliny, Book II.), but owing to its inflammability it is unfit for use. Bitumen should be extremely brilliant, heavy and massive, and is commonly adulterated with pitch.

Its medical qualities are similar to those of sulphur, being naturally astringent, dispersive, contractive, and agglutinating. Ignited it drives away serpents by the smell.

Babylonian bitumen is very efficacious, it is said, for the cure of cataract, leprosy and other affections. Bitumen is employed, too, in the form of a liniment for gout. Applied with nitre, it is curative

of toothache, and taken internally with wine it alleviates chronic coughs and difficulties of respiration. It is applied in a similar manner for dysentery. Taken internally with vinegar it dissolves and brings away coagulated blood. It modifies pains in the loins and joints, and applied with barley meal it forms a peculiar kind of plaster. It also stanches blood, heals wounds and unites severed sinews. Bitumen is administered for quartian fevers in doses of one drachma, mixed with an equal quantity of mint, the whole kneaded up with one obolus of myrrh. The smell of burnt bitumen detects a tendency to epilepsy.

Another use that is made of it is for coating the inside of copper vessels as a protection against the action of fire.

In Book IV., chap. 9, Pliny informs us that bitumen was used as a stain or preservative for coating statues. It has also been used as a substitute for lime in building the walls of Babylon and elsewhere, as well as a varnish for coating iron, heads of nails, etc. (see Pliny's Natural History, translated by John Bostock, M.D., F.R.S.).

A.D. 80.—Josephus (Bellum Judaicum I., 33, 5) states that Herod the Great, when dying of an internal disease, visited the Dead Sea and there bathed in a vat of asphaltic oil, on the advice of his doctors.

A.D. 155–235.—Dion Cassius the historian, writing about A.D. 200 (in Book 41, section 45), also alludes to the flaming well in Apollonia (referred to above), adding that neighbouring people regarded this Nympheum as an oracle, and cast their offerings into the fire. If the offerings were consumed it augured a favourable response to their prayers, but if they were rejected the reverse. So discriminating were the flames that if the offerings were acceptable, and were placed anywhere near the well, the flames would dart out and consume them, but if unacceptable they were rejected even if flung right into the fire. Information regarding marriage or death, however, was not obtainable in this manner.

A.D. 615.—Benjamin Smith Lyman, in his report of progress for the first year of the Geological Surveys of the Oil Lands of Japan, 1877, pages 17–35, states that: "It is said that the oldest wells of Echigo were here (Kusodzu), and they are supposed by the inhabitants to have been dug several hundred years ago. It is said in the Japanese history called Kokushiriyaku (I am told) that rock oil or 'burning water' was found in Echigo in the reign of Tenjitenno, which was 1,260 years ago and about A.D. 615; and that was probably at Kusodzu, where there are still very old natural exposures as well as dug wells. The name of the place, Kusodzu, is the name given in the country to rock oil, and means stinking water; and the very fact that the word is by contraction

so much changed from its original form, kusai midzu, shows of itself considerable antiquity. Natural gas even is called kazaku-sodzu, the first two syllables meaning wind or air, and evidently identical etymologically with our very modern western word gas, . . . which is at any rate clearly identical in its turn with the German word geist and the English ghost—spirit, the Latin spiritus, breath or breeze."

A.D. 668.—It is very interesting to read in the book entitled "Mining in Japan—Past and Present" (published by the Bureau of Mines, Department of Agriculture and Commerce of Japan, 1909), that: "In A.D. 668, petroleum and asphaltic substances were offered to the Court of the Emperor Tenji from the province of Echigo, . . . and that the zeal of the Emperor Monmu for mining industry was so intense that he took the initiative for the issuing of the mining law, which is known in the famous code 'Taihorei,' issued in June A.D. 701."

10th Century A.D.—An unknown author in a treatise on farming (Geoponica XVII., 16, 1) states that bramble leaves smeared with bitumen were given to cattle as a cure for diarrhœa.

Stephanus in his Thesaurus Græcæ states that "rock oil, or oil that flows from rocks," was used in ancient times for a lighting oil in "lieu of olive oil, the more usual medium," and quotes from Platearius (a professor of Botany at Salerno) a quasi scientific explanation of its origin that "Rock oil is formed when the richness of earth and water is transformed by the action of heat into a fiery substance," and adds that "it is formed on stones because it sweats out through them and from them, and that it is formed upon walls, but of a black colour, though afterwards by dint of thorough baking it turns white."

A.D. 1347–1445.—In the Chronicum Tergenseense (the records of the Monastery of Tergens in Bohemia) occurs the following passage: "Over against the afore-mentioned chapel the brethren discovered a vein of petrol oil (vena olei petrolei) which has now been flowing for about forty years. Persons (afflicted) with palsied and shrivelled limbs smeared with this oil, have in many cases been restored to their former health."

A.D. 1556.—Georgius Agricola's "De Re Metallica," 1556 (English translation by H. C. and L. H. Hoover, 1912), Book XII., page 581, states that: "Bitumen is made from bituminous substances. The water, bituminous as well as salty, at Babylon, as Pliny writes, was taken from the wells to the salt works and heated by the great heat of the sun, and condensed partly into liquid bitumen and partly into salt. The bitumen being lighter, floats on the top, while the salt being heavier, sinks to the bottom. Liquid bitumen, if there is much floating on springs, streams and

rivers, is drawn up in buckets or other vessels; but, if there is little, it is collected with goose wings, pieces of linen, ralla, shreds of reeds, and other things to which it easily adheres, and it is boiled in large brass or iron pots by fire and condensed."

On this the translators comment in a footnote: "The substances referred to under the names bitumen, asphalt, maltha, naphtha, petroleum, rock-oil, etc., have been known and used from most ancient times, and much of our modern nomenclature is of actual Greek and Roman ancestry. These peoples distinguished three related substances: the Greek asphaltos and Roman bitumen for the hard material; Greek pissasphaltos and Roman maltha for the viscous, pitchy variety, and occasionally the Greek naphtha and Roman naphtha for petroleum proper, although it is often enough referred to as liquid bitumen or liquid asphaltos. The term petroleum apparently first appears in Agricola's De Nature Fossilium (page 222), where he says the 'oil of bitumen . . . now called petroleum.' Bitumen was used by the Egyptians for embalming from prehistoric times—*i.e.*, prior to 5000 B.C., the term 'mummy' arising from the Persian word for bitumen, mumiai. It is mentioned in the tribute from Babylonia to Thotmes III., who lived about 1500 B.C. (Wilkinson, Ancient Egyptians I., p. 397). The Egyptians, however, did not need to go further afield than the Sinai Peninsula for abundant supplies."

A.D. 17th Century.—C. F. Menestrier, a seventeenth century antiquarian, on page 6 of his history of Lyons, quotes from an ancient charter of that city (A.D. 1022) an allusion to a fountain of petroleum: see Ducange under reference "Petroleia Fons."

A.D. 1613.—In the book entitled "Mining in Japan—Past and Present" (referred to above), on page 25 it is said that the utilisation of the natural gas from the oil-fields of Garameki village, Kanbara County (Echigo), was projected early in A.D. 1613.

A.D. 1629.—Mr. S. F. Peckham, in his Report on the Production, Technology and Uses of Petroleum and its Products to the U.S. Census Office in 1882, mentions that the existence and certain uses of petroleum were well known to the Indians dwelling in the vicinity of the great lakes, but the earliest mention is of 1629, when a Franciscan missionary, Joseph de la Roche D'Allion, wrote a letter in which he mentions the oil springs and gives the Indian name of the place, which he explained to mean "there is plenty there." This letter was published in Sagard's Histoire du Canada, 1632.

He also quotes from the first volume of the Massachusetts Magazine, published in 1789: "In the northern part of Pennsylvania is a creek called Oil Creek, which empties into the Allegheny River. It issues from a spring, on which floats an oil

similar to that called Barbadoes tar, and from which one may gather several gallons in a day. . . ."

A.D. 1665.—J. Jonston, in his "Thaumatographia naturalis," p. 146 (Amsterdam, 1665), alludes to Bitumen Terrenum or Lithanthrax called Pharmacitis, as being found in Scotland. He further quotes the following from Nicolas Monardes, who published a valuable work "De simplicibus medicamentis ex Occidentali India delatis" at Antwerp in A.D. 1574: "In Callao, provincia Peruana, is found a bituminous soil, which the native Indians dig from the ground, and expose the sods arranged on poles and short reeds to the heat of the sun, from which drips a liquor which is caught in bowls, and used for many diseases. The residue is then used as fuel."

A.D. 1681.—On the 19th August, 1681, a patent was granted to John Joachun Becher, Dr. of Law, of the Parish of St. Martin's-in-the-Fielde, and Henry Serle of Lincolnes Inne, Esq.: as, after long study, labour and expense, they had discovered ". . . a new way of makeing pitch and tarre out of Pitt Coale, never before found out or vsed by any other." This patent was granted ". . . under our Great Seale of England to empower and enable them to put in execucon the said Invencon to continue for the terme of fourteen years . . . in our Kingdome of England or Dominion of Walls."

18th Century A.D.—Thomas, tenth Earl of Dundonald, in his "Autobiography of a Seaman," Vol. I., 1860, pages 37-40, alludes to his father's sanguine expectations of retrieving the family estates by his discoveries, which led him to embark in a multitude of manufacturing projects, and says: "That an enumeration of some of my father's manufacturing transactions, extensively and simultaneously carried on, will leave no doubt as to their failure in a pecuniary sense. First, the preparation of soda from common salt, as a substitute for barilla—till then the only alkali available for soap and glass making, . . . the preparation of sal ammoniac . . . a new process of extracting tar and other products from pit-coal; the former as an effective agent in protecting timber from decay, whilst the refuse coke was in request amongst iron-founders, whose previous operations for its manufacture were wasteful and unsatisfactory."

He comments in a footnote that: "Whilst serving on the west coast of Africa, my father remarked the destructive ravages made on ships' bottoms by worms, and, from his chemical knowledge, it occurred to him that an extract from pit-coal, in the form of tar, might be employed as a preventative of the evil. On his return home, the experiment was tried and found to answer perfectly. Notwithstanding the subsequent refusal of the Admiralty to make

use of his preservative, it was at once adopted by the Dutch and elsewhere in the North, and in the case of small coasting vessels is to this day used in our own country, as less expensive than coppering. Had not the coppering of vessels become common shortly afterwards, the discovery must have proved of incalculable value." (Archibald, ninth Earl of Dundonald, in his early life served, first of all, in the Navy and then in the Army, and afterwards gave that up to follow his scientific experiments.)

He also says: "Cavendish had some time previously ascertained the existence of hydrogen. Priestley had become acquainted with its inflammable character, but the Earl of Dundonald may fairly lay claim to the practical application of its illuminating power in a carburetted form. In prosecution of his coal-tar patent, my father went to reside at the family estate of Culross Abbey, the better to superintend the works on his own collieries, . . . an experimental tar-kiln was erected near the Abbey, and here coal-gas became accidentally employed in illumination. Having noticed the inflammable nature of a vapour arising during the distillation of tar, the Earl, by way of experiment, fitted a gun-barrel to the eduction pipe leading from the condenser. On applying fire to the muzzle, a vivid light blazed forth across the waters of the Frith, becoming, as was afterwards ascertained, distinctly visible on the opposite shore. The incident just narrated took place about the year 1782."

He also adds that a paper on the "Utility and Advantages of Gas-lights," written by Mr. Murdoch, was read before the Royal Society on the 25th February, 1808, detailing the lighting of Messrs. Phillips and Lee's manufactory at Manchester, and describing the process of gas manufacture.

19th Century A.D.—It is also mentioned in the book entitled "Mining in Japan—Past and Present" (already referred to) that "Petroleum in Echigo was formerly obtained from ditches excavated along the outcrop, as seen at Kurokawa, which was, however, changed in A.D. 1818, to the pit sinking method. The primitive method of the hand dug wells had been used everywhere and particularly the two following methods, which are called 'Tebori' and 'Kadzusabori.'"

"'Tebori' or hand dug well is a primitive method, sinking a square pit 4 to 6 feet in width. This well is used in such places where oil-bearing bed is very shallow, where thin layers yielding oil exist, or where the surface water is rare. The depth of the wells of this kind is less than 600 feet, and it is commonly found to be very difficult to work them deeper."

"'Kadzusabori' is an improved Chinese method of boring which is worked by the human labour only, without any aid from

a machine. The derrick for this well is 30 feet in height. The characteristic points of this well are as follows : a bamboo pole is employed instead of the working beam, its elasticity being utilised in drilling the well. The split bamboo, jointed to required length, is also used instead of both the drilling cable and the sand line. One end of the bamboo rope is wound to the wooden wheel from 12 to 18 feet in diameter, which is turned by three workmen, and by the rotation of which the drilling tools or the sand-pump joined to the other end may be let fall down the well or raised up to the surface."

" On the favourable condition of the strata, the depth of this well may be carried down to 1000 feet. Although this process needs much time for the work of boring, it is still used now, on account of the fact that its arrangement is very simple and its expense is comparatively small. On the average, the number of workmen employed are four in the Tebori and five in the Kadzusabori, while the American rope drilling system needs at least eight workmen. The American rope drilling was first put into practical operation in 1890, at the Amaze district in Echigo province, and as a result, a spouting well was struck at the beginning of the following year."

About this time was the commencement of the " Meiji "—era of enlightenment.

A.D. 1861.—Abraham Gesner, in his " Practical Treatise on Coal, Petroleum and other distilled Oils," pages 9–11, states that " in 1847 patents were granted in England, to Charles Mansfield for ' an improvement in the manufacture and purification of spirituous substances and oils applicable to the purposes of artificial light.' His operations appear to have been chiefly directed to the coal tar of gas works, from which he obtained benzole ; and to James Young, of Manchester, who secured a patent in England on the 7th October, 1850, and subsequently in the United States, on the 23rd March, 1852, for ' the obtaining of paraffine oil, or an oil containing paraffine, and paraffine from bituminous coals.' " He also mentions that the total number of patents granted, with inventions and improvements claimed for the manufacture and purification of oils from coals and other bituminous substances, since 1781, are more than one hundred in number, and upwards of forty patents have been granted for retorts, stills, and other apparatus connected with this branch of industry. He also quotes : " In 1761 oils were distilled from black bituminous shale, and were employed in the cure of certain diseases, as stated in Lewis's ' Materia Medica ' for that year."

A.D. 1877.—Mr. B. S. Lyman, in his report, 1877, already referred to, says : " Reviewing all the Echigo oil fields we find that there

are in all 522 productive wells, of which the deepest is 122 fathoms (732 feet) deep; and the greatest yield is about 1·2 barrels (koku) a day; and the total yield about 26 barrels . . . a day; giving an average of about two gallons (5 shô) a day for each well. . . . In Shinano, on the other hand, the yield is still far smaller. There are in that province, in spite of the numerous traces of oil and gas, only 22 productive wells, of which the deepest is 57 fathoms deep, and the best has a yield of 2½ barrels a day . . . and the total yield is a little over five barrels a day, or an average of 9½ gallons (23·3 shô) a day to each well. . . . The whole yield of the two provinces then is about equal to that of two average oil wells of Pennsylvania."

A.D. 1886.—Boverton Redwood, in his Cantor Lectures on "Petroleum and its Products" delivered before the (now "Royal") Society of Arts, in 1886, page 2, states that in 1765 the English Government sent an embassy to the Court of Ava, in Burmah, and in the Journal of the Embassy Major Symes thus refers to the petroleum wells in the neighbourhood of the Yenangyoung (Earth-oil Creek), a small tributary, of the Irrawaddy: "After passing various lands and villages, we got to Yenangyoung, or Earth-oil Creek, about two hours past noon. We were informed that the celebrated wells of petroleum which supply the whole empire and many parts of India with that useful product, were five miles to the east of this place. The mouth of the creek was crowded with large boats waiting to receive a lading of oil, and pyramids of earthen jars were raised in and around the village, disposed in the same manner as shot and shell are piled in an arsenal. This is inhabited only by potters, who carry on an extensive manufactory, and find full employment. The smell of the oil is extremely offensive. We saw several thousand jars filled with it ranged along the bank; some of these were continually breaking, and the contents, mingling with the sand, formed a very filthy consistence."

He also quotes on page 13 that Mr. Peckham, in his Report to the U.S. Census Office in 1882, states that petroleum, including its solid and gaseous forms, occurs: "On the American continent along a line extending from Point Gaspe, in Canada, to Nashville, Tennessee, and in Europe-Asia along a line extending from Hanover, on the North Sea, through Galicia, the Caucasus, and the Punjab. These are the principal lines. In America it also occurs on the Pacific Coast, from the bay of San Francisco to San Diego; again, from Northern Nebraska to the mouth of the Sabine River, on the Gulf of Mexico; again, from Havana, near the western end of Cuba, through San Domingo, and the circle of the Windward and Leeward Islands, to Trinidad; thence westward on the main-

land to the Magdalena River, and southward from that point to Cape Blanco, in Peru. In Europe-Asia bitumen occurs on the lower Rhine, and in the valley of the Rhone ; from northern Italy, following the Apennines, to southern Sicily ; along the eastern shores of the Adriatic, through Dalmatia and Albania, into Epirus ; again along the depression in which lies the Jordan and the Dead Sea ; again, along the mountains that border the valley of the Tigris in the east ; again from western China, through Burma, Pegu, Assam, Sumatra, and Java : and lastly, in Japan. It will be observed that these lines are, for the most part, intimately connected with the principal mountain chains of the world."

Oil Storage Tanks.

By F. A. Trim (Associate Member).

Petroleum and its products are usually stored in steel tanks, either set directly upon the ground, as is the case on refinery tank farms, or placed in an underground concrete vault when the installation is within city limits. Occasionally oil is stored in large earth reservoirs, but this practice has been found to be somewhat wasteful on account of seepage and evaporation, and is only used in cases of emergencies such as are met with in the oil field. Concrete lined tanks or reservoirs are in successful operation along the Pacific Coast of the United States for the storage of crude oils. Sizes are on record up to 750,000 bbl. capacity, and the construction of a 3,000,000 bbl. reservoir is contemplated for one of the large companies in California.

It is proposed in this paper to deal only with the steel storage tanks as in use on refineries or large storage depots, for it is impossible to cover comprehensively the subject involving the various types of tanks as used in the different branches of the oil industry.

Construction of tanks has not reached by any means the advanced stage of standardization set by many other industries. The oil companies still largely make up their own specifications and, naturally, no two purchasers' requirements are alike. As such it is intended to outline a few general principles covering tank design and construction leading toward standardization and not to treat any individual specification.

Steel storage tanks installed on large tank farms, etc., are generally of the cylindrical type and vary in size from 10 ft. 0 in. to 200 ft. 0 in. in diameter, and from 15 ft. 0 in. to 40 ft. 0 in. high. The following table gives the various sizes that have been generally adopted by the large oil companies :—

Diameter. ft.	in.	Height. ft.	in.	Capacity. Gallons.
116	0	30	0	2,000,000
82	6	30	0	1,000,000
65	0	30	0	600,000
50	0	40	0	500,000
40	0	30	0	225,000
30	0	25	0	100,000
25	0	15	0	45,000
20	0	15	0	30,000
15	0	10	0	10,000
10	0	10	0	5,000

The larger sizes are being favoured more, not only because they cost less per gallon storage capacity, but the cost of fire-walls, piping arrangements, etc., amounting to a considerable item, is practically the same for any size tank. All things considered, it is possible by adopting larger sizes to obtain the same class of storage at a less cost.

The general arrangement for an ordinary cylindrical tank of moderate dimensions is shown in Fig. 1. The walls are constructed

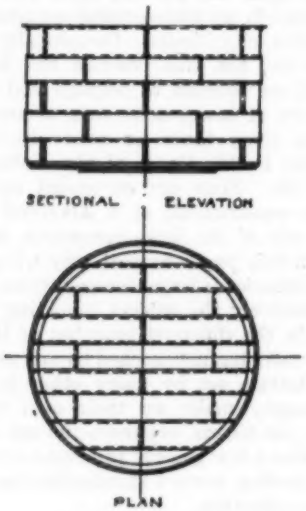


FIG. 1.

in strakes, the plates of which are from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. in thickness, the circumferential seams constructed always of single riveted lap joints, and on the vertical seams where the plates are over $\frac{1}{2}$ in. thick, butt joints are used. A stout angle forms the bottom curb connecting the shell with the flat floor plating of $\frac{1}{4}$ in. to $\frac{3}{8}$ in. in thickness, and a light angle curb is usually provided at the brim to take the edge of the roof sheets. The roof is invariably of the "Conical" or "Umbrella" type as shown in Figs. 2 and 3. With tanks of small dimensions the roof sheeting of 14 B.W.G. is supported on light steel trusses spanning the full diameter of the tank and intersecting at the centre. On the larger sizes, and where foundations permit, it is preferable to use a centre post or stanchion with the trusses radiating from it to the outside.

Close attention is being paid to the rendering gas tight of tanks, especially those used for the storage of light oils, and process tanks, in order to eliminate losses caused through evaporation. The roof plates are then riveted at close pitch and welded where they join the angle curb.

Wood roofs are and will undoubtedly still be used for crude oil tanks. Such roofs, however, cannot be made gas tight, and also materially increase the fire risks.

When tanks are made gas tight it is essential that some sort of relieve valve be fitted to the roof. There are now on the market one or two valves that admirably suit this purpose, operating both on pressure and vacuum. One valve in particular, operated by two non-corrosive springs, is positive in action and capable of very

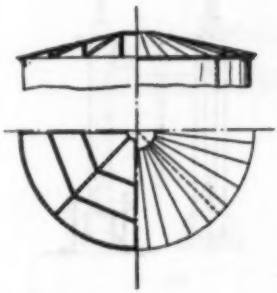


FIG. 2.

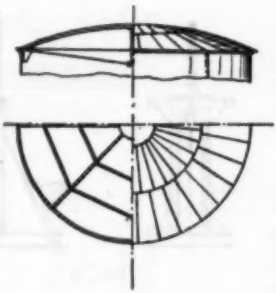


FIG. 3.

accurate adjustment such as is necessary when in use on tanks connected to an absorption or compression petrol recovery plant.

Another type of valve finding favour amongst refinery engineers is one employing valve discs, one for vacuum and the other for pressure, and adjusted by means of weights attached to fulcrum levers. The range of adjustments is from 0·23 to 4·14 lb./sq. ft. below atmospheric pressure and from 0·7 to 5·53 lb./sq. ft. above atmospheric pressure.

Ladders are used to give access to the roof for gauging and inspection, but on the larger size tanks the safety movement favours stairways built to the shell. Double handrailing is recommended for the outer edge of the roof to afford protection to dippers and maintenance men working thereon.

To afford adequate lightning protection by having a good earth connection, it is common practice to elongate a few of the handrail stanchions to gain this end.

Tank fittings, such as the side manholes, cleaning doors, inlet and outlet stools, are made in cast steel. Cast iron is used for the roof fittings, dipping doors, hinged manholes, etc.

It is the usual practice to have a separate inlet and outlet connection to the tank. Some companies call for a flap valve to be fitted on the inside at the inlet opening. Its only advantage is that in the event of any external connection being broken, the valve will close from the inside and cut off any flow of oil.

Swing pipes attached to the draw off connection are usually fitted as standard. A common type of swing pipe is that operated by means of a wire cable passing through a vapour tight entrance

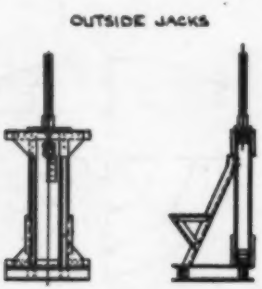


FIG. 4.

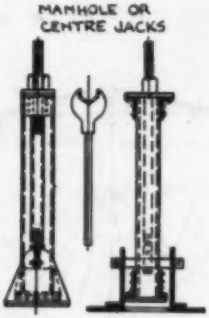


FIG. 5.

bushing in the roof and down to a small ratchet winch at the side of the tank.

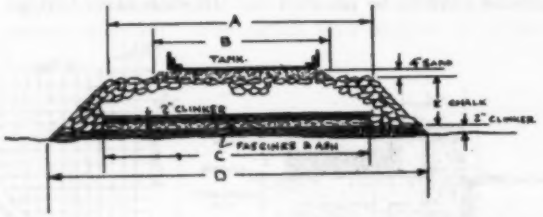
In erecting the tank, the bottom is laid, riveted and caulked on trestles or horses about thirty inches above the foundation. The first ring or strake is erected while the bottom is thus elevated. Before lowering, the bottom and curb is given two coats of protective paint. Ship's bottom or heavy asphalt paint is generally used. Jacks of the screw type are then bolted to the shell and the inside floor manholes. All the horses and debris are removed from underneath, and the bottom then gradually lowered until it is firmly on the foundation. Figures 4 and 5 show the type of outside shell and inside manhole jacks that are used for this purpose.

Two systems of scaffolding are in use for assembling the outer shell and to enable the riveting and caulking to be done. Where water is available, floating scaffolds are used to a great extent, the water being pumped into the tank as fast as the shell is caulked, raising at the same time the scaffolding to the required level. In other cases rivet holes in the shell are used to take light steel

brackets on the inside and outside, on which the scaffold planks are laid. After service these holes are riveted up. Some manufacturers make provision for this type of scaffolding by having special holes punched in the sheets.

All tanks should be tested with water to detect any leaks before being painted or accepted for service. While this test is necessary, it will not guarantee against absolute tightness. It will, however, indicate important leaks, and those of a small nature can always be made good at a later date.

When light oil tanks are connected to a recovery plant or where they are to be made completely gas tight, it is usual to carry out



Size of tank' Dia. × height.	A.	B.	C.	D.	E.	Fascines Lgth. of	Chalk in tons.
15′ 0″ × 8′ 0″ ..	21′ 0″	15′ 0″	21′ 0″	25′ 0″	2′ 0″	9′ 0″	30
25′ 0″ × 10′ 0″ ..	31′ 0″	25′ 0″	34′ 0″	36′ 0″	2′ 6″	9′ 0″	78
30′ 0″ × 10′ 0″ ..	36′ 0″	30′ 0″	39′ 0″	41′ 0″	2′ 6″	9′ 0″	103
25′ 0″ × 20′ 0″ ..	31′ 0″	25′ 0″	34′ 0″	37′ 0″	3′ 0″	9′ 0″	96
20′ 0″ × 10′ 0″ ..	26′ 0″	20′ 0″	31′ 0″	31′ 0″	2′ 6″	9′ 0″	56
50′ 0″ × 30′ 0″ ..	53′ 6″	50′ 0″	59′ 0″	63′ 6″	3′ 6″	12′ 6″	350
40′ 0″ × 25′ 0″ ..	46′ 6″	40′ 0″	49′ 0″	53′ 6″	3′ 6″	12′ 6″	243
82′ 6″ × 30′ 0″ ..	90′ 0″	82′ 6″	91′ 6″	97′ 0″	3′ 6″	12′ 6″	850

FIG. 6.

the test for air tightness at the same time as the water test is on. While the water is at its full height the roof is tested by compressed air at a pressure of 3-in. water gauge, being maintained for a period of 30 min. with the air supply and all vents tightly sealed. While under pressure all seams, rivets, etc., are brushed with soapy water, and any leakages detected by same made tight.

In connecting up temporary water lines to the tanks for testing purposes, precautions should be taken to see that any existing lines that have been in use for pumping oils are thoroughly cleansed before using them to pump water to the tanks. In a long length of line, sufficient quantity of oil in a film on the inside will be found when pumped with water into a tank with all vents closed, to cause an explosive mixture under the roof. Neglect of these

precautions has met with disastrous results and it is further recommended, especially when a roof is to be tested for air tightness, or when any hot rivets are to be used during the test, to have the air underneath the roof tested and certified to be free from oil vapours before any work of the above nature is carried out.

In most cases where the ground has a good bearing surface, the tanks are set directly upon the ground without preparing any special foundation other than levelling the site. Where the ground is of a soft or muddy nature, settling foundations composed of chalk and fascines are in wide use. Fig. 6 gives the dimensions for this class of foundation and indicates clearly its construction.

In locations such as on swampy ground, concrete mat and piling foundations have to be resorted to. In such cases borings should

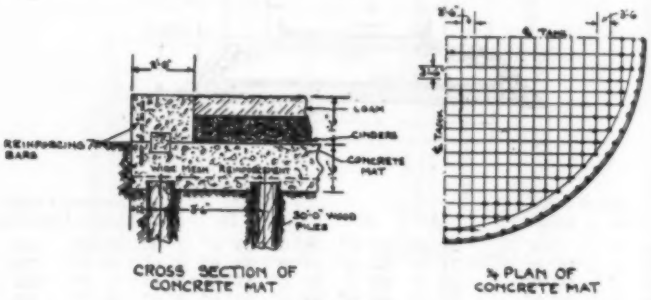


FIG. 7.

be made on the proposed site to ascertain the nature of the subsoil and to enable an efficient and economical design to be carried out. The number of piles, depth of the mat, etc., are influenced by local conditions, and no standard form of design for this type of foundation can be laid down to suit all conditions. One form of concrete mat and pile foundation for a large size tank is shown in Fig. 7 and shows clearly the cross section of the mat and spacing of piles common to this design.

In the case of tanks erected upon settling foundations, strict attention is paid to the settling of the tank when under water test, and periodical inspection followed up for some months after the tank has been put in service. A procedure often adopted is to take sight levels at eight or more points around the tank, or at each vertical seam on the lower strake. At these points wooden blocks are inserted under the curb angle to provide a seating for the levelling staffs. These are levelled with a spirit level just before any transit levels are taken. When the tank is two-thirds full of

water, one complete day's rest should be given, after which levels are again taken at the various points and compared with the previous readings. Filling the tank is then continued at the rate of three feet a day, levels being taken and compared at intervals. The settling should have ceased before running off the water, which should remain in the tank for as many days up to a week as may be necessary after it has been approved tight. Permanent bench marks are usually employed and arranged in convenient positions around the tank farm for the sighting levels on the various tanks at the least number of stations as is possible. Records should be kept of all the levels taken and in such form as to enable periodical checking to be kept up with ease.

Painting of the tanks after having been accepted for storage is given special attention. The entire tank should be allowed to

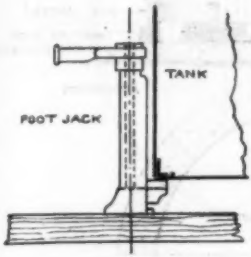


FIG. 8.

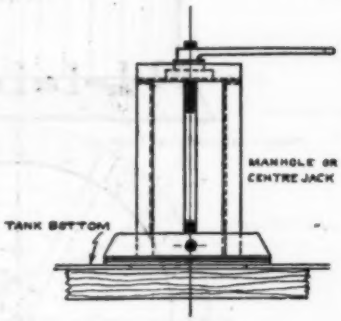


FIG. 9.

weather for at least two months, after which all scale should be removed by scraping the entire shell with wire brushes. It should then be given at least two coats of a good priming paint. Red lead ground in pure linseed oil makes an excellent primer, as well as being a good preservative, and some of the marketed special graphite paints are found to serve equally as well. For the finishing coats on the light oil tanks, light battleship grey seems to be the universal colour. Some companies in addition paint the entire lower strake of the tank black, for the rain splashing around the foundations will throw up a lot of chalk and sand wash and disfigure it. However, this is done for appearance sake and is in no way essential. Crude or heavy oil tanks are usually painted in black throughout.

In cases where the tank bottom has caved in, or out of plumb, and when it is necessary to remake the foundation, the tank must be

lifted to undertake this work. This has been carried out successfully by raising with outside foot and bottom manhole jacks of the screw type as shown in Figs. 8 and 9. The number of jacks required depends upon the size of the tank and its weight. For illustration purposes an arrangement for positioning the jacks for lifting a large tank and the scheme for entrenching the foundation is shown in Fig. 10.

To prevent undue strain being placed upon the floor plating while the tank is raised, the manhole covers in the bottom are removed

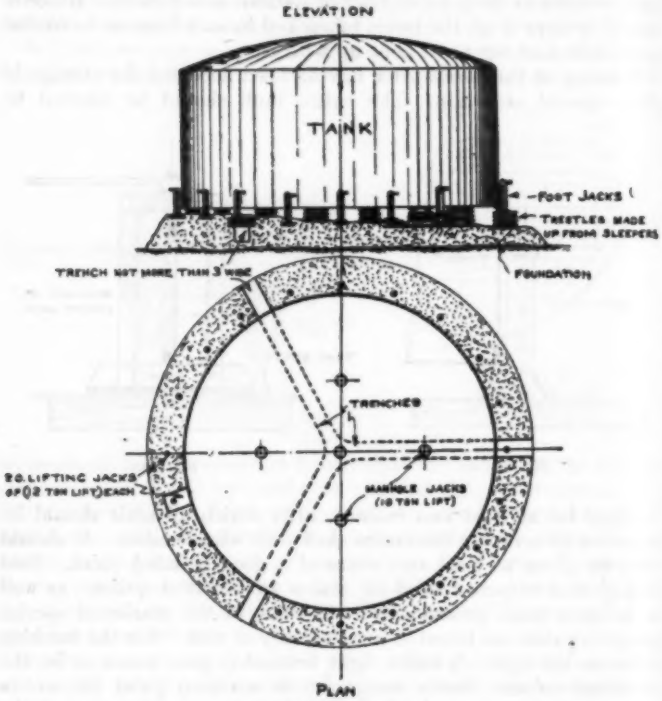
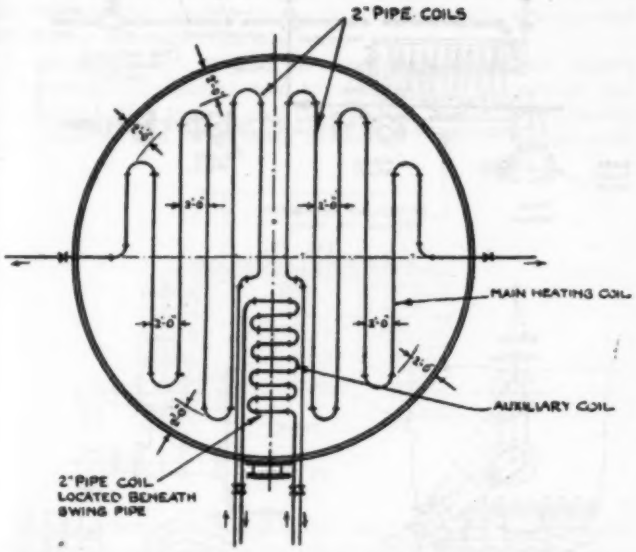


FIG. 10.

and the manhole jacks bolted in place. With all the jacks working simultaneously, the tank is raised steadily, sleepers being placed in trestle form at convenient points underneath and at the side. This enables the bottom to be supported and left level until the new foundation is completed. Trenches about 3 ft. wide are dug

from the centre to the outside of the foundation for running the skip cars used in excavating and remaking the foundation. As this is continuing, the sleepers are removed until the jacks alone bear the weight. The jacks are then lowered in the same manner as raising until the tank settles to its foundation.

Many oils, more especially those stored in tanks above ground, have to be heated before they can be successfully pumped. Box



HEATING COIL FOR 100,000 GAL TANK

FIG. 11.

coils of 2 in. pipe and return bends have been found to accomplish this very satisfactorily. The piping is divided into two main and one auxiliary coils. Once the oil is heated, the auxiliary coil will provide sufficient heat to enable the discharge to take place at a nominal rate. Fig. 11 shows the arrangement of this type of heater as fitted to a 100,000 gallon tank.

For small fuel oil tanks, such as are employed for supplying Diesel engines and oil burners, a small heater such as that illustrated in Fig. 12 has given excellent results. A temperature control valve is employed in its operation, thus enabling the oil

to be maintained at the right degree of temperature with a minimum consumption of steam.

Piping connections to the tanks should receive special care, more especially to those where settling will take place. All fittings from the inlet and outlet stools and tank valves or at any place where

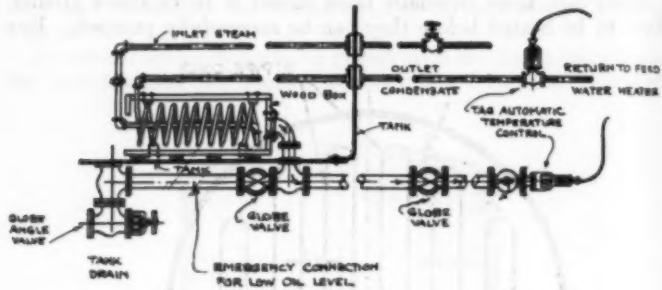


FIG. 12.

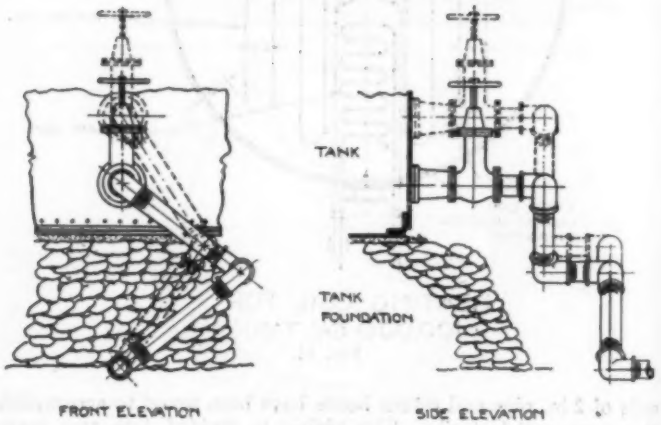


FIG. 13.

there is liable to be contact with the foundation, swivel fittings should be installed so as to allow the pipe connection to move freely when the tank settles and thus take off any strains and prevent breakage.

An effective and non-expensive method of arranging pipes connecting to the tank to meet the above purpose, and which has

been tried out with success, is shown in Fig. 13. Standard screwed fittings take the place of swivel joints.

On tanks where the sludge cocks or drain fittings are installed under the bottom at the outer edge, the foundation is dug away so as to give free movement to these fittings and provide room for pipe connections. Fig. 14 shows clearly how this is carried out and the boarding up of the cavity. If a large part of the foundation is removed, it is advisable to place one or two steel beams across the opening so as to distribute the unsupported weight over the entire foundation.

In considering the problem of evaporation, American refiners are favouring the floating roof type of tank to accomplish this desired end. This type of roof reduces to a minimum practically all evaporation loss, in so much as the air is not in contact with

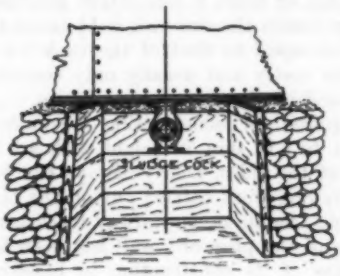


Fig. 14.

the oil and offers many advantages over the gas-tight canopy roof tank because it is equally effective when continually being filled and emptied.

In the roof of this type of tank, the float is the main body and is made up in steel plates, the diameter being about 12 in. smaller than that of the shell. Trussing and tie rods are employed to maintain the roof in a level line. A seal is used for joining the roof to the shell in sliding contact. It consists in some designs of a shoe with the same curvature as the tank, and bevelled in such a way as to slide over rivets and seams, and is supported by hangers so disposed as to cause its weight to be thrown against the tank. Gas-tight canvas connects the top of the shoe with the float. In other designs the canvas is replaced by a trough around the float containing oil which forms a liquid seal and prevents any leakage of vapours from underneath the float into the atmosphere. Drainage of the roof is taken care of by a syphon

which conducts the water from the roof to a well in the bottom of the tank, and is drawn off whenever necessary through a pipe leading to the outside. A difficult problem which had always confronted the designer of this type of roof was in centering the float at the varying oil levels within the shell, such as when it is out of level or where the diameter is long in one place and short in another. This, however, appears to have been overcome satisfactorily by using spring plungers or buffers in conjunction with the float rollers, and enables the flexible shoe of the float to be kept in contact with the shell at the varying levels.

To comply with the petroleum authorities and insurance companies' requirements, it is necessary to build an earth or masonry fire-wall around all tanks containing oil so as to prevent any flow of oil from one tank to another or surrounding property as would occur in a tank fire or when a connection becomes broken. The required capacity within the fire-wall is 1½ times that of the tank for earth walls, or equal to that of the tank for masonry walls. Masonry walls are costly and usually only considered when tank spacing is close and confined to narrow limits.

The earth required for constructing fire-walls, which in size average 2 ft. 0 in. to 4 ft. 0 in. in height with a 3 ft. 0 in. top and a 1½ to 1 slope at the sides, nearly always can be had from the excavating or levelling work carried out on the tank site or other parts of the plant. Small gauge railway track carried on wooden trestles alongside of the proposed wall has been found to be well worth the expense of its construction in handling the material for building these walls. Tipping cars are used for dumping the material, which need only be handled by labour in tamping and finishing the wall to the required dimensions.

Fire hydrants, steam lines, etc., leading to the tank for fire-fighting purposes should have all operating connections placed outside of the fire-walls so as to be accessible in case of fire.

In conclusion, the writer would state that although the subjects of "Volume Measurement of Tanks" and "Fire Protection," as applied to tank farms and refineries in general, are closely allied to the subject of this paper, it is his belief that they should be treated separately under "Movements of Oil" and "Fire Protection," which play so great a part in the operation of all modern oil installations.

REVIEWS.

Die Automobile Treibmittel des In- u. Auslandes (Motor Spirits at Home and Abroad). By Dr. Erwin Sedlaczek. (Julius Springer, Berlin. 247 pp.)

The book consists of a review of patent literature dealing with fuels for motor engines. It is divided into four parts: the first deals with German, Austrian and Swiss patent literature, and the other three with French, American and British patents respectively. Each part is subdivided into sections treating of petroleum products, coal-tar products, alcohol, aldehyde, ketone, and a miscellaneous class of fuels containing hydrogenated products and synthetic mixtures. The book is very concise in style and covers a very great number of patents. The inventors' names are not given with the patents, nor is there any index of names in the book, an addition which would have made the book more useful as a book of reference. The volume will be of considerable assistance to the rather limited circle of research workers engaged on fuels for internal combustion engines.

HAROLD MOORE.

Successful Asphalt Paving. By P. J. M. Larrañaga. Pp. xiii. + 255. Published for the Author by Richard Clay and Son, Ltd., London, 1927. 12s. 6d.

The author has edited his "collected notes" and has produced not only a vigorous piece of propaganda in favour of asphalt road construction in general and "the modern synthetic asphalt paving" in particular, but he has also put into print a mass of manufacturing and laboratory details which, if not all new, are seldom published in the practical form that has now been adopted.

The book is attractive for the unusual clearness with which the nature of the problems are viewed and made clear, and the entertaining and even humorous way in which the subject has been lightened.

The nature of bitumen and its colloidal properties are set forth with excellent simplicity, and considerations of the complicated property of consistency are also well demonstrated.

Mr. Larrañaga expresses high approval of the Melting-Point Test (Ball and Ring) and of the Ductility Test, the latter being developed into a means of investigation as well as of identification. The Penetration Test should be swept away as the purchaser does not "intend using the bitumen to make pin-cushions." He has little use for the Carbene Test, and has unexpectedly little to say about Viscosity determinations.

The most important portion of the book is taken up with practical details of manufacturing, laying and controlling, through the laboratory, the various types of asphalt road mixtures. Of these he has his favourite, and the rest are not treated kindly. Granite setts and wood blocks are more vigorously denounced, but real war is carried into the enemy's camp in a full-blooded attack on concrete.

A rather long Appendix includes most of this attack, as well as statistics, model specifications (of considerable stringency), a controversy about slippery roads, descriptions of laboratory tests, and two patents of which, perhaps, even Mr. Larrañaga has not heard much. The book terminates with an efficient index.

In the presentation of such a complex matter as the scientific understanding and efficient construction of asphalt roads, it is to be expected that a clash of views will occur and errors creep in. The former will probably be found to be few and to refer to relatively unimportant details, such as the author's approval of the centrifugal separator and disapproval of an open binder course. More severe is his scolding of Trinidad bitumen and Clifford Richardson. Of errors, there seem to be very few, either of fact or through misprints, but there seems to be one in connection with *Ductility* on page 167.

The book is to be recommended as being stimulating, thought-provoking, practically useful, and trustworthy when obvious exuberances are recognised.

PERCY E. SPIELMANN.

THE SUBJECT INDEX TO PERIODICALS, 1922. K. SCIENCE AND TECHNOLOGY. Pp. 138. The Library Association, London, October, 1926. £1 1s. net.

By the examination of 300 periodicals published during 1922, the Library Association has compiled a very valuable bibliography of over 6000 entries relating to published articles of scientific and technical interest. The entries are arranged under subject headings, cross referenced where necessary, and the whole forms a useful and ready means of tracing articles, published during the particular year, on a very wide range of subjects.

GEORGE SELL.

BOOKS RECEIVED.

REPORT OF TESTS ON THE FREEMAN MULTIPLE RETORT. Department of Scientific and Industrial Research. Pp. 35. London: H.M. Stationery Office, 1926. 1s. net.

The report covers tests carried out by the Fuel Research staff from June to November, 1925, on the Freeman multiple retort erected at the works of British Oil and Fuel Conservation, Ltd., at Willesden. The retort, as modified by the staff, is capable of carbonising up to 6 tons of bituminous low-caking coal per 24 hours, the yield of dry tar at the normal temperature of 500° C. being higher than any other yet observed by the Fuel Research Staff. Full details of the tests, the materials used and the results obtained are given.

REPORT OF THE FUEL RESEARCH BOARD FOR THE YEAR 1925. Department of Scientific and Industrial Research. Pp. 79. London: H.M. Stationery Office, 1926. 1s. 3d. net.

This report, which includes also the Report of the Director of Fuel Research, deals with the work of the Fuel Research Division of the Department of Scientific and Industrial Research during 1925.

ERRATA.

"Oil Finding by Geophysical Methods," W. H. Fordham, Vol. XI., No. 52, pp. 448-470.

Equations U_{xx} and U_{xy} at the bottom of page 456 should read:

$$U_{xx} = 10^{-9} \times \sigma\,(35{\cdot}8c_1 + 9{\cdot}15c_2 + 2{\cdot}81c_3 + 1{\cdot}47c_4 + 0{\cdot}940c_5 + 0{\cdot}407c_6 + 0{\cdot}099c_7)$$

$$U_{xy} = 10^{-9} \times \sigma\,(35{\cdot}8b_1 + 9{\cdot}15b_2 + 2{\cdot}81b_3 + 1{\cdot}47b_4 + 0{\cdot}940b_5 + 0{\cdot}407b_6 + 0{\cdot}099b_7)$$